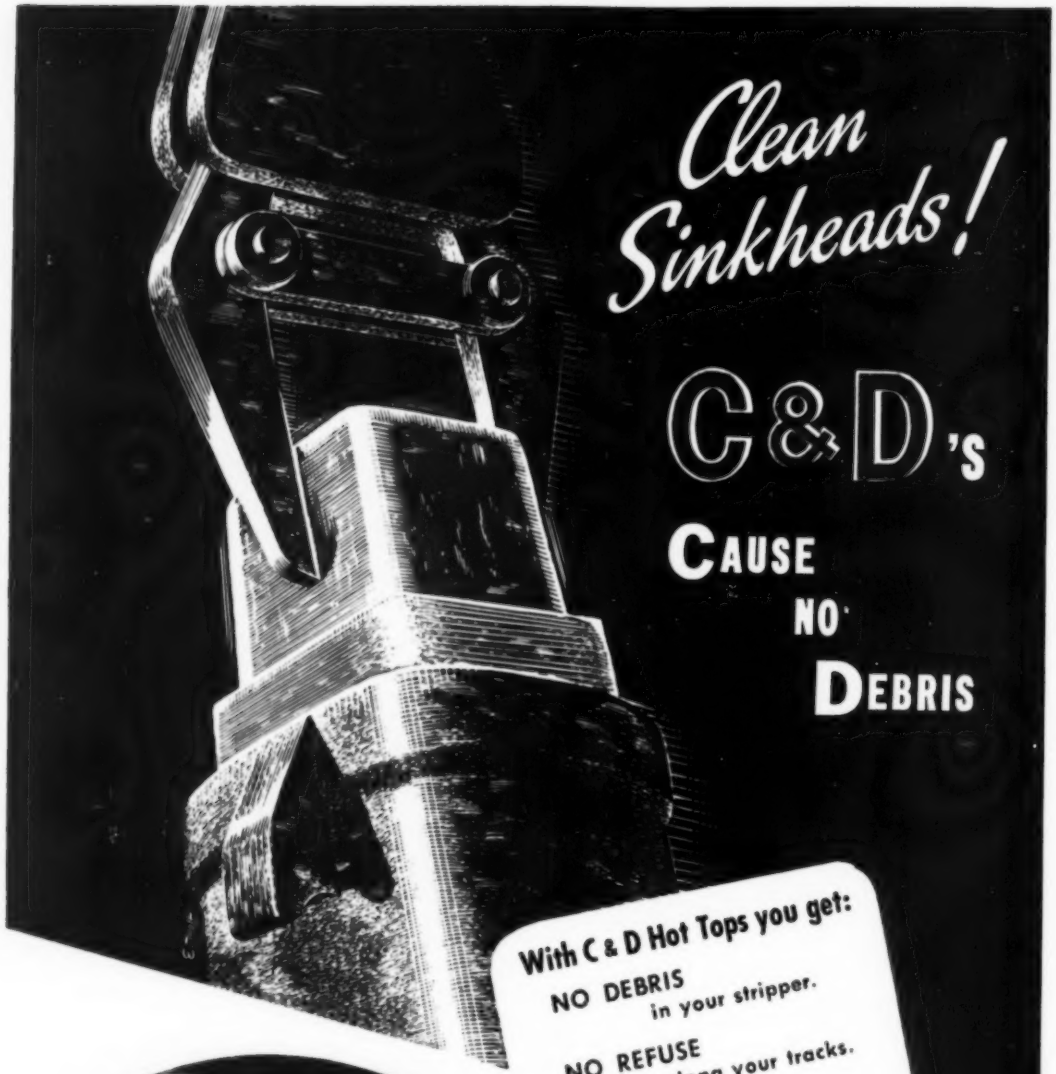
APRIL, 1953

Journal of METALS

Blast Furnace, Coke Oven and Raw Materials

Annual Conference — Program Number

National Open Hearth Steel Committees



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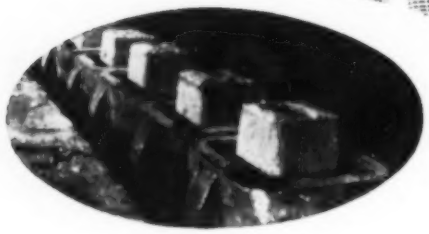

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Journal of METALS

VOL. 5, NO. 4 APRIL, 1953

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the metals industry by the
Metals Branch
American Institute of Mining and Metallurgical Engineers, Inc.
29 West 39th Street, New York 18

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COVER

Kaiser Steel is the only fully integrated steel plant on the Pacific Coast having its own coke ovens and blast furnaces. The mill is laid out on an 1800-acre site which will permit expansion to several times the size of its original facilities. When the present expansion program is completed, Kaiser Steel will be the twelfth largest steel producer in the nation. The aerial view shows the rolling mills in the foreground, the open hearth building and the blast furnaces in the center; and at center right, the new 9-acre tinplate mill.

36th STEELMAKING CONFERENCE

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Published the first day of each month by the American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $8 per year for non-AIME members in United States and North, South and Central America; $10, foreign; $6 for AIME members, or $4 additional in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology". Single copies, 75 cents; single copies foreign, $1.00; special issues, $1.50 . . . The AIME is not responsible for any statement made or opinion expressed in its publications. . . . Copyright 1953 by the American Institute of Mining and Metallurgical Engineers, Inc. . . . Registered cable address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index and Chemical Abstracts . . . Reentered as second-class matter Sept. 21, 1949, at the post office at New York, N. Y., under the Act of March 3, 1879. Additional entry established at Manchester, N. H.

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ELECTROMET *Data Sheet*

Published by Electro Metallurgical Company, A Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario.

ALLOYS FOR THE STEEL, IRON, AND NON-FERROUS INDUSTRIES

PRODUCT*	NOMINAL COMPOSITION	USES
BORON ALLOYS		
Ferroboron		
Min. 10.00% Boron Grade	Silicon.....max. 1.50% Aluminum.....max. 0.50% Carbon.....max. 1.50%	Increases hardenability of steel; also, for additions to malleable iron and aluminum alloys.
Min. 17.50% Boron Grade	Silicon.....max. 1.50% Aluminum....max. 0.50% Carbon.....max. 0.50%	
Manganese-Boron	Boron.....min. 17.50% Manganese...approx. 75% Silicon.....max. 1.50% Carbon.....max. 3% Iron.....max. 5%	Used to cleanse and deoxidize non-ferrous alloys.
Nickel-Boron	Boron.....15 to 18% Silicon.....max. 1.50% Aluminum.....max. 1.00% Carbon.....max. 0.50% Iron.....max. 3.00% Nickel.....Balance	Special boron alloy used principally for deoxidizing nickel and its alloys.
Boron Carbide	Boron.....45 to 50% Carbon .....45 to 50%	Deoxidizer for non-ferrous alloys.
Calcium Boride	Boron.....38 to 42% Calcium.....27 to 32% Carbon.....15 to 20%	Welding rod coating.
CALCIUM ALLOYS		
Calcium-Silicon	Calcium.....30 to 33% Silicon.....60 to 65% Iron.....1.50 to 3%	Deoxidizer for quality ingot steel. Also used in high-tensile gray irons.
Calcium-Manganese-Silicon	Calcium.....16 to 20% Manganese.....14 to 18% Silicon.....53 to 59%	A complex deoxidizer used widely in production of steel castings.
Calcium Metal		Reducing agent in metallurgical applications, deoxidizer and degasifier for non-ferrous metals, particularly magnesium.
Regular Grade	Calcium.....98% (Cylinders, Slabs, Cut Pieces, or Turnings)	
Distilled Grade	Calcium...approx. 99.90% (Irregular pieces from pea size to 14 in. lumps)	For special applications requiring calcium of very high purity.
CHROMIUM ALLOYS		
Low-Carbon Ferrochrome	Chromium.....67 to 71% Silicon.....0.30 to 1.00% Carbon (10 Grades) max. 0.03 to max. 2.00%	Production of stainless steels and high-temperature alloys requiring low carbon content.
High-Carbon Ferrochrome		
Max. 4.50, 5.00, or 6.00% Carbon Grade	Chromium.....67 to 70% Silicon..... 1 to 2%	For production of engineering alloy steels and other alloy steels of moderate chromium content.
Max. 7.00% Carbon Grade	Chromium.....66 to 69% Silicon..... 1 to 3%	
Min. 7.00% Carbon Grade	Chromium.....65 to 68% Silicon..... 1 to 3%	
Nitrogen-Bearing Low-Carbon Ferrochrome	Chromium.....67 to 71% Silicon.....0.30 to 1.00% Carbon.....max. 0.10% Nitrogen....approx. 0.75%	For additions of nitrogen to improve properties of high-chromium steels.
"SM" Ferrochrome	Chromium.....60 to 65% Silicon ..... 4 to 6% Carbon..... 4 to 6% Manganese..... 4 to 6%	A high-solubility chromium addition for steel or iron in either furnace or ladle.
Exothermic Ferrochrome	Chromium....60% approx. Carbon.....4.5% max.	An improved exothermic ladle alloy with high solubility, low carbon pickup, and high ignition temperature.
Exothermic Silicon-Chrome	Chromium... 46% approx. Silicon..... 23% approx. Carbon.....1.00% max.	An improved exothermic ladle alloy with high solubility, very low carbon pickup, and high ignition temperature.

PRODUCT*	NOMINAL COMPOSITION	USES
CHROMIUM ALLOYS cont.		
Foundry Ferrochrome		Developed especially for high-solubility ladle additions of chromium to improve composition and properties of cast iron.
High-Carbon Grade	Chromium.....62 to 66% Silicon..... 7 to 10% Carbon..... 5 to 7%	
Low-Carbon Grade	Chromium.....50 to 54% Silicon.....28 to 32% Carbon.....max. 1.25%	
Chromium Metal		Production of wide variety of non-ferrous chromium-bearing alloys, including electrical resistance alloys and high-temperature alloys.
Low-Carbon Grades	Chromium.....min. 97% Carbon .....max. 0.10% and 0.50% Iron.....max. 1%	
High-Carbon Grade	Chromium.....87 to 90% Carbon..... 9 to 11% Iron.....max. 1.25%	
"EM" Ferrochrome-Silicon		In production of stainless steels, these alloys are used to reduce metal oxides from the slag back into bath.
No. 1 Grade	Chromium.....39 to 41% Silicon.....42 to 46% Carbon.....max. 0.05%	
No. 2 Grade	Chromium.....36 to 39% Silicon.....36 to 39% Carbon.....max. 0.05% Aluminum..... 7 to 9%	
"EM" Ferrosilicon-Chrome	Chromium.....50 to 54% Silicon.....28 to 32% Carbon.....max. 1.25%	For adding chromium and silicon to steels containing up to 1 or 2 per cent chromium.
"EM" Chromium Briquets (Hexagonal Shape)	Chromium.....2 lb. Total Weight.....3⅛ lb.	For adding chromium to cast iron in the cupola.
COLUMBIUM ALLOYS		
Ferrocolumbium	Columbium.....50 to 60% Silicon.....max. 8% Carbon.....max. 0.40%	Stabilizer in austenitic chromium-nickel stainless steels. Also constituent of high-temperature alloys.
Ferrotantalum-Columbium	Columbium...approx. 40% Tantalum.....approx. 20% Cb+Ta .....min. 60% Silicon.....4 to 6% Carbon.....max. 0.30%	Another stabilizer, used to supplement ferrocolumbium, in austenitic chromium-nickel stainless steels. Also used in high-temperature alloys.
MANGANESE ALLOYS		
Standard Ferromanganese		Most common means of adding manganese to steel for both alloying and deoxidizing purposes. Also for counteracting sulphur in steel and cast iron.
Regular Grade	Manganese.....78 to 82% Carbon.....approx. 7% Silicon.....max. 1%	
Low-Phosphorus Grade	Manganese.....78 to 82% Carbon.....max. 7% Silicon.....max. 2% Phosphorus...max. 0.10%	
Low-Carbon Ferromanganese		Additions of manganese to steels of low-carbon specification, particularly stainless steels of 18 per cent chromium, 8 per cent nickel type.
Low-Phosphorus Grade	Manganese.....min. 90% Carbon.....max. 0.07% Phosphorus...max. 0.06%	
Regular Grades	Manganese.....85 to 90% Carbon ....max. 0.07, 0.11 to 0.15, 0.30, or 0.50%	
Regular Grade (High-Silicon)	Manganese.....80 to 85% Carbon.....max. 0.75% Silicon..... 5 to 7%	
Medium-Carbon Ferromanganese	Manganese.....80 to 85% Carbon.....max. 1.25 to 1.50%	For making low- and medium-carbon manganese steel and Hadfield steel.
Silicomanganese		A versatile alloy useful as furnace block, deoxidizer, and also for making manganese additions to steel in the ladle or in the furnace.
Max. 1.50% Carbon Grade	Manganese.....65 to 68% Silicon.....18 to 20%	
Max. 2.00% Carbon Grade	Manganese.....65 to 68% Silicon.....15 to 17.50%	
Max. 3.00% Carbon Grade	Manganese.....65 to 68% Silicon.....12 to 14.50%	

*All of the alloys and metals listed are produced in the usual lump, crushed, or ground sizes, except where other special forms are indicated.

PRODUCT*	NOMINAL COMPOSITION	USES
MANGANESE ALLOYS cont.		
Low-Iron Ferromanganese	Manganese.....85 to 90% Carbon.....approx. 7.00% Silicon.....max. 3% Iron.....max. 2%	For high manganese additions to certain non-ferrous alloys, particularly aluminum.
Manganese Metal	Manganese.....min. 96% Carbon.....max. 0.20% Silicon.....max. 1.00% Iron.....max. 2.50%	Used both as deoxidizer and alloy in production of numerous non-ferrous metals and alloys.
"EM" Silico-manganese Briquets (Square Shape)	Manganese.....2 lb. Silicon.....½ lb. Total Weight.....3½ lb.	For adding manganese (with silicon) to cast iron in the cupola.
"EM" Ferro-manganese Briquets (Oblong Shape)	Manganese.....2 lb. Total Weight.....3 lb.	For adding manganese (without silicon) to cast iron in the cupola.
SILICON ALLOYS		
50% Ferrosilicon		
Regular Grade	Silicon.....47 to 51%	Deoxidizer for most grades of killed or semi-killed steel. Blocking grade specially sized for maximum efficiency.
Blocking Grade	Silicon.....47 to 51%	
Low-Aluminum Grade	Silicon.....47 to 51% Aluminum.....max. 0.40%	
65% Ferrosilicon		
Regular Grade	Silicon.....65 to 70%	For furnace or ladle addition to carbon and alloy steels.
Low-Aluminum Grade	Silicon....61.50 to 66.50% Aluminum.....max. 0.50%	Mainly for production of electrical sheet steel.
75% Ferrosilicon		Deoxidizer and alloy for production of high-silicon spring and electrical sheet steel. Graphitizing inoculant for cast iron.
Regular Grade	Silicon.....73 to 78%	
Low-Aluminum Grade	Silicon.....73 to 78% Aluminum.....max. 0.50%	
85% Ferrosilicon		Enables melter to add higher percentages of silicon without chilling metal in ladle. Graphitizing inoculant for cast iron.
Regular Grade	Silicon.....83 to 88%	
Low-Aluminum Grade	Silicon.....83 to 88% Aluminum.....max. 0.50%	
90% Ferrosilicon		Permits large additions of silicon without harmful chilling effect.
Regular Grade	Silicon.....92 to 95%	
Low-Aluminum Grade	Silicon.....92 to 95% Aluminum.....max. 0.50%	
Silicon Metal		Additions of silicon to non-ferrous metals, particularly aluminum and copper, to improve physical properties.
Regular Grade	Silicon.....min. 97 or 96% Iron.....max. 1 or 2%	
Purified Grade	Silicon....99.70 to 99.90% Iron.....005 to .015%	For applications in non-ferrous industry requiring silicon of high purity.
Low-Calcium Grade	Silicon.....min. 97% Iron.....max. 1% Calcium.....max. 0.10%	For the production of high-silicon aluminum alloys where calcium is detrimental.
Low-Aluminum Grade	Silicon.....min. 98% Iron.....max. 1% Aluminum.....max. 0.10%	For the production of silicon-copper alloys where aluminum is detrimental.
"SMZ" Alloy	Silicon.....60 to 65% Manganese..... 5 to 7% Zirconium..... 5 to 7%	Particularly strong graphitizing inoculant used in making ladle additions to cast iron.
Special Graphitizer	Ferrosilicon Compound	Deoxidizer and graphitizer for cast iron.
Magnesium-Ferrosilicon	Silicon.....approx. 46% Magnesium..approx. 8.5%	For ladle addition to cast iron to obtain special properties.
Barium-Silicon	Barium.....40 to 50% Silicon.....45 to 55%	For deoxidation of non-ferrous alloys.
"EM" Silicon Briquets (Cylindrical Shape)		
Large Size	Silicon.....2 lb. Total Weight.....5 lb.	For adding silicon to cast iron in the cupola.
Small Size	Silicon.....1 lb. Total Weight.....2½ lb.	

"Electromet," "EM," "SM," and "SMZ," are trade-marks of Union Carbide and Carbon Corporation.

PRODUCT*	NOMINAL COMPOSITION	USES
TITANIUM ALLOYS		
Ferrotitanium	Titanium.....27 to 32% Carbon .....max. 0.10%	For stabilized austenitic stainless steels and high-temperature metals.
Silicon-Titanium	Titanium.....40 to 50% Silicon.....45 to 50% Iron.....max. 3%	For additions of titanium to steels or non-ferrous alloys.
Manganese-Nickel-Titanium	Titanium.....43 to 48% Nickel.....approx. 25% Manganese.....max. 8%	Deoxidization of nickel alloys.
TUNGSTEN ALLOYS		
Ferrotungsten	Conforming to A.S.T.M. Spec. A 144-39	For production of tool and die steels; also high-temperature alloys.
Tungsten Metal Powder		Production of tungsten steels and cast tungsten carbide.
Melting Grade	Tungsten....min. 98.80% Total Carbon..max. 0.25%	
Calcium Tungstate	Tungstic Oxide..68 to 72%	For making tungsten chemicals and other tungsten products.
Calcium Tungstate Nuggets	Tungstic Oxide..68 to 72%	Making tool steels and high-temperature alloys by direct reduction.
Ammonium Paratungstate	Tungstic Oxide..min. 88.7%	Intermediate for tungsten products.
VANADIUM ALLOYS		
Ferrovanadium	Vanadium.....50 to 55% Carbon....max. 0.20, 0.50, or 3.00% Silicon....max. 1.50, 2.00, or 8%	Production of tool and engineering steels, high-strength structural steels, non-aging rimming steels, and wear-resistant irons.
Vanadium Oxide Fused	V_2O_5.....86 to 89% Na_2O.....approx. 10% CaO.....approx. 2%	For addition of vanadium to steel and for manufacturing catalysts.
Sodium Polyvanadate (Red Cake)	V_2O_5.....approx. 85% Na_2O.....approx. 9% CaO.....approx. 2% H_2O.....approx. 2.5%	For manufacture of vanadium compounds, including vanadium catalysts.
High-Purity Ammonium Metavanadate	V_2O_5.....approx. 99.50% NH_4VO_3.....min. 99%	
ZIRCONIUM ALLOYS		
12 to 15% Zirconium Alloy	Zirconium.....12 to 15% Silicon.....39 to 43% Carbon.....max. 0.20%	This is a powerful deoxidizer. It also increases depth of hardening.
35 to 40% Zirconium Alloy	Zirconium.....35 to 40% Silicon.....47 to 52% Carbon.....max. 0.50%	Deoxidizer for fine grades of alloy steels. Used for adding larger amounts of zirconium.
Nickel-Zirconium	Zirconium.....25 to 30% Nickel.....40 to 50%	For deoxidizing and degasifying nickel alloys.

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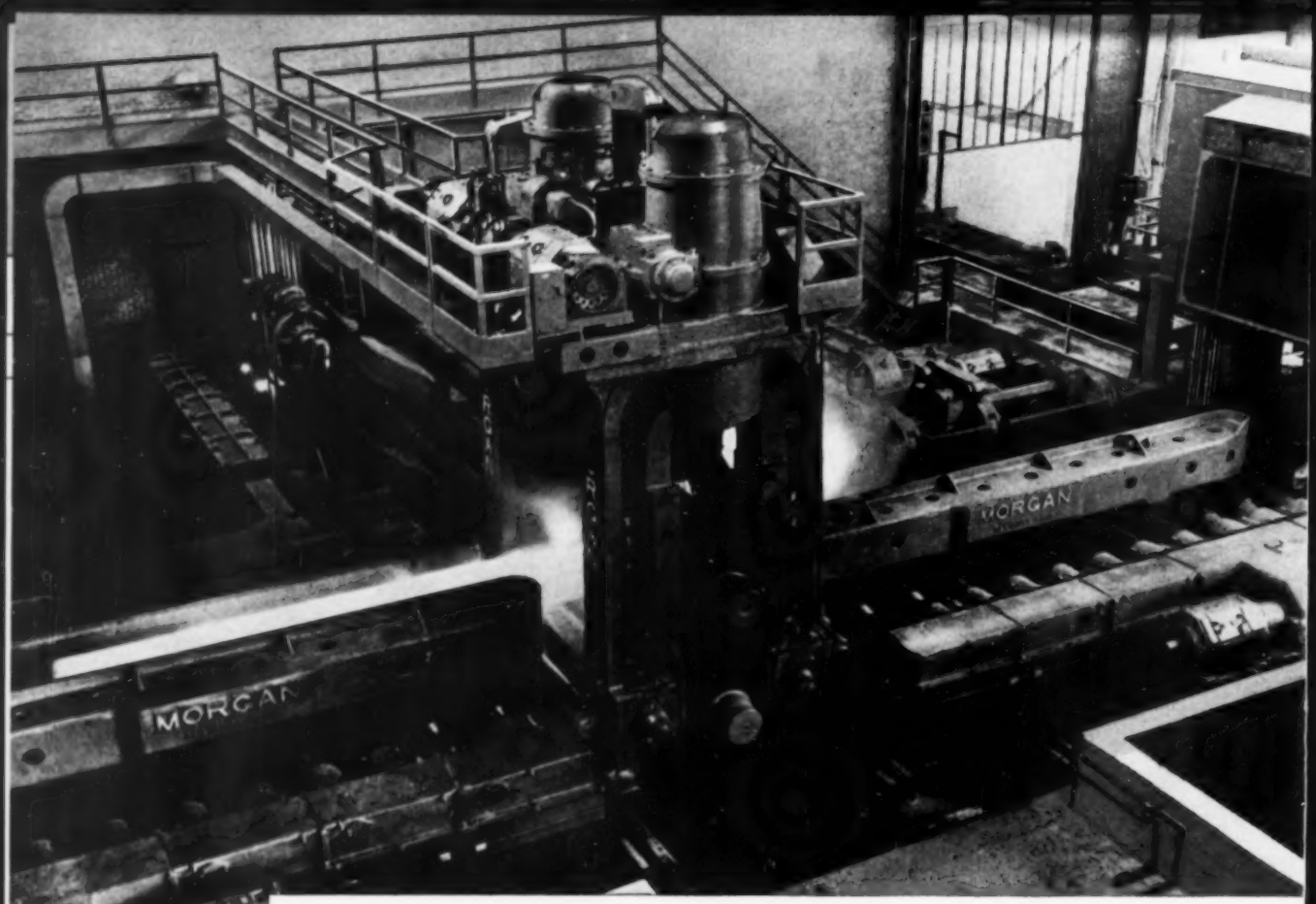

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Meet The Authors

J. E. ANDERSEN

D. G. EBELING

J. E. Andersen (p. 554), a native of Cheshire, England, received his B.A. Sc. and M.A. Sc. degrees from the University of British Columbia. In May 1951 he was metallurgical engineer with Sherritt-Gordon Mines and since October 1952 has been shift supervisor in the pilot plant of the metallurgical research div. Now residing at Hull, Quebec, Mr. Andersen counts bowling, fishing, and electronics as his hobbies.

Dolph G. Ebeling (p. 537) is a native New Yorker and graduated from Rensselaer Polytechnic Institute (B.S., M.S., Ph.D.). Dr. Ebeling was employed by the Carnegie-Illinois Steel Corp. in 1940 prior to going into the Navy. During 1941 to 1946 he was a member of the technical staff of the Naval Proving Ground. After his discharge, he joined the General Electric Co. in the Carboloy dept. working on the development and production of permanent magnet alloys. He also did some graduate work at Carnegie Institute of Technology. A Member of AIME his winter hobby is skiing and in the summer he recovers from the effects of skiing. He is presently at the GE research laboratory, Schenectady, studying high temperature alloys.

J. HERENGUEL

A. A. BURR

J. Herenguel (p. 559) is a graduate of the University of Lille. Born in Lens, France, Dr. Herenguel is presently director of research services, Societe des Trefileries et Laminois du Havre, Antony, Seine, France. He has been director of the research center since the society was organized in 1945.

A. A. Burr (p. 537) is an associate professor at Rensselaer Polytechnic Institute. Born at Saskatchewan, Canada, he taught school there from 1933 to 1936. He was a graduate assistant at Pennsylvania State College and for three years Dr. Burr was associated with the Armstrong Cork Co. as a research physicist. He became a member of the faculty of RPI in 1946 as an assistant professor and in 1949 was named an associate professor. Dr. Burr holds B.A., M.A., and Ph.D. degrees from the University of Saskatchewan and Pennsylvania State College. His hobbies are fishing, photography, and woodwork. In addition to being an AIME Member, he belongs to the ASM, American Physics Society, ASEE, American Ordnance Assn., and American Non-Destructive Testing Society.

PAUL LACOMBE

P. LELONG

Paul Lacombe (p. 559) was recently appointed professor of general metallurgy and director of the metallurgy research center at the Ecole Nationale Superieure des Mines, Paris. Dr. Lacombe was born at Lille, France and is a graduate of the University of Paris, Sorbonne. In 1942 he was appointed chief metallurgist at the Central Commercial Laboratory, Vitry, Seine. He was appointed maitre de recherches of Centre National de la Recherches Scientifique in the same laboratory. He holds membership in the Societe Francaire de Metallurgie and Institute of Metals, London. Dr. Lacombe enjoys alpine climbing and water color painting as his hobbies.

P. Lelong (p. 559), associated with the research center of the Societe des Trefileries et Laminoirs du Havre, was born at St. Omer, Pas-de-Calais, France. He received his degrees from the Institut de Chimie de Lille in 1947. Mr. Lelong has been with the society since 1948. In his spare moments he enjoys photography.

H. A. Saller (p. 545) is a graduate of Purdue University (1940, B.S.). Mr. Saller is presently supervisor, special materials at Battelle Memorial Institute. For one year he was a metallurgical observer at the Gary works of Carnegie Illinois Steel Corp. He joined the staff of Battelle in 1941 as research engineer. He was then named assistant supervisor and is now supervisor. *Relative Deoxidizing Powers of Some Deoxidizers for Steels* is the title of a paper he previously presented. As his hobbies, Mr. Saller enjoys music and woodworking.

J. Halpern (p. 554) is an assistant professor of metallurgy at the University of British Columbia, Vancouver. Prof. Halpern was born in Poland and attended McGill University, Montreal (B.Sc. and Ph.D.). In 1949 he was a post-doctorate fellow in the dept. of physical chemistry at the University of Manchester, England. Dr. Halpern is a member of the Chemical Institute of Canada. *The Reaction of Silver with Aqueous Solutions of Cyanide and Oxygen* is the title of a paper previously submitted to AIME.

F. A. Rough (p. 545) has been associated with Battelle Memorial Institute since 1948, where he is now assistant supervisor. Born in Mt. Vernon, Ill., Mr. Rough attended the University of Illinois (B.S. and M.S.). Among his hobbies, Mr. Rough counts sports and reading.

F. C. Hull (p. 565) was born at Alliance, Ohio and received his B.S. in 1937 from the University of Michigan. In 1941 he obtained his D.Sc. from the Carnegie Institute of Technology. During the years 1937 to 1939, Dr. Hull was a teaching assistant at Carnegie. He was a Westinghouse Research Fellow at Carnegie from 1940 to 1941 and then joined the Westinghouse organization as a research engineer. In 1951 Dr. Hull was named manager of the metallurgical section at East Pittsburgh. Dr. Hull is an AIME member who plays golf. He plays duplicate bridge and enjoys gardening. A member of ASM and ASTM, he has previously presented papers before AIME.

B. S. Lement (p. 530), who received S.B. and Sc.D. degrees from Massachusetts Institute of Technology, is now on the research staff of metallurgy at that school. He has also been connected with Watertown Arsenal and the Universities of Massachusetts and Notre Dame. This member of AIME, ASM, and Sigma Xi enjoys tennis, chess and bridge.

S. C. Das Gupta (p. 530), born in Barisal, East Pakistan, studied at Scottish Church College, the Bengal Engineering College, Calcutta University, Calcutta, India and the Missouri School of Mines and Metallurgy. He recently completed work for his Ph.D. in metallurgy at the University of Notre Dame and is now located at Calcutta.

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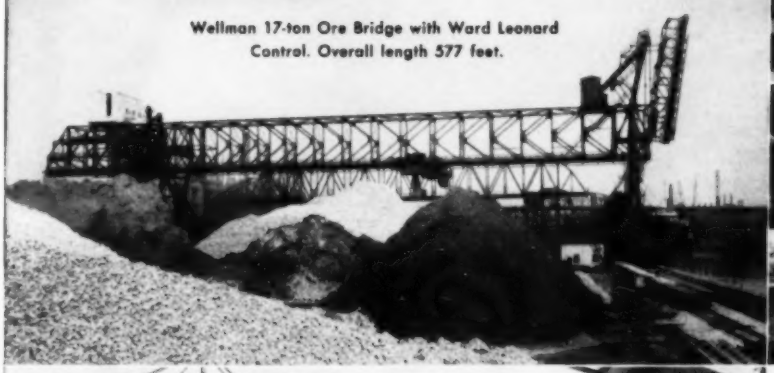
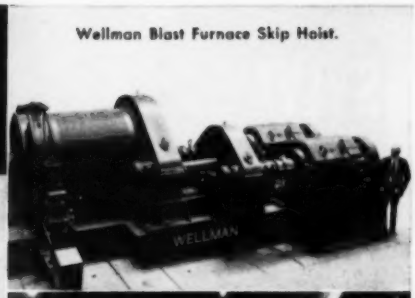
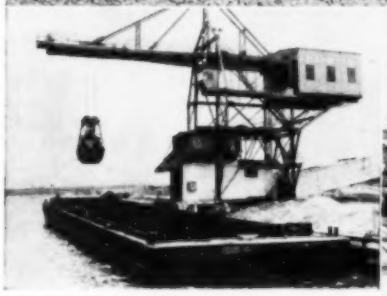


Wellman Blast Furnace Skip Hoist.

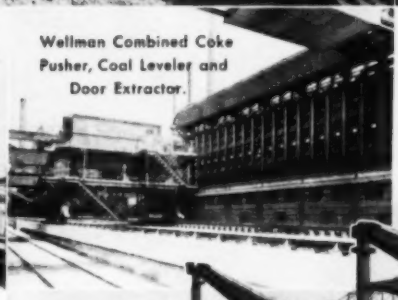


Wellman 7½-ton low type Open Hearth Charging Machine.

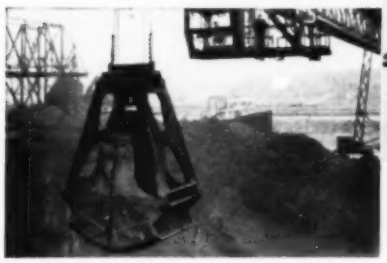


Wellman Tower Unloading Crane with 6¾-ton Williams-type Bucket.

Wellman Combined Coke Pusher, Coal Leveler and Door Extractor.



Wellman 17-ton Hulett-type Ore Unloaders with Ward Leonard Control.



Wellman "Williams" Type 17-net-ton Ore Bucket.

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MEN AVAILABLE

Metallurgist, university graduate in metallurgical engineering. Over two years' in responsible position small Brazilian lead-silver smelter. One year in research on leaching and precipitation procedures for certain base metals. Canadian. Age 27, married, one child. Speak Portuguese fairly well, Spanish slightly. Prefer foreign work. M-103.

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Director of Metallurgical Research, 35 to 40, Ph.D. or equivalent, to administer and act as chief executive on pure research and different types of metals. Salary, $15,000 to $18,000 a year. Y8302(a).

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Consultant with mechanical and/or metallurgical engineering experience in the following field: Extrusion of solids and hollow shapes; tube reducing and drawing of heavy and light seamless tubing. The materials involved are special nonferrous metals such as titanium and zirconium. Experience on these metals not essential. Full or part-time. Location, Pennsylvania. Y8273.

Development Engineer, metallurgical degree, with good foundation in mechanical design. Previous work in aluminum field helpful. Will assist project engineers in applications of bonded aluminum—ferrous bi-metals to wide diversity of products. Salary open. Location, East. Y8272.

Production Superintendent, over 35, metallurgical degree preferred, with technical proficiency and substantial experience in the field of powder metallurgy. Salary, $10,000 to $12,000 a year. Location, Midwest. Y8265-D-8294.

Engineers. (a) Assistant chief engineer, 35 to 40, experienced in medium to heavy metal processing. Should know tooling and design for production. Should be good administrator, as applicant will eventually head department. Salary open. (b) Sheet metal engineer, 35 to 40, with considerable experience in the application of sheet metal such as is used in refrigerators, cabinets, deep freezers, etc. Will also eventually head department. Salary open. Location, Ohio. Y7914.

METALLURGIST. Position available to graduate metallurgist with 2 to 3 years' practical experience. 25 to 35-year age bracket preferred; however, will train recent college graduate. Please respond with statement of experience and background.
ATHENIA STEEL DIVISION,
National-Standard Co.,
Clifton, New Jersey

Metallurgist to run a mill, with tin and tungsten experience. Salary, $8000 to $9000 a year. Location, Alaska. Y8004.

Chemical or Metallurgical Engineer, under 30, for liaison duties between laboratory of company producing fuel pumps, carburetors, and other automotive components and customers. Should be able to meet and deal with people, analyze trouble and make logical recommendations regarding product improvement. Salary, $4800 a year. Location, East. Y7890-D8139.

Production Engineer with mechanical or metallurgical engineering training and at least ten years' stainless steel strip mill experience. Salary, $8000 to $10,000 a year. Location, Canada. Y8213.

Assayer to take charge of large laboratory. Should have had five to ten years' experience in the assaying of precious metals. Salary open. Location, northern New Jersey. Y7929S.

Project Engineer, not over 50, for household appliance development. Must have minimum of five years' experience on processing of metal, particularly sheet metal, and ability to carry through from inception. Salary, $8000 a year or better. Location, Wisconsin. Y8007CD.

Junior Executives, experience in machine tool or heavy metalworking industry desirable. Will work closely with department head and with customers or suppliers in one of the following phases of the business: Contract terms, delivery dates, scheduling of machine installation and servicing repair parts. Purchasing and scheduling delivery of necessary electrical and hydraulic equipment initially, and later, patterns, rough materials and all other supplies; supervising the development of better electrical controls for general purpose machines; keeping up with new improvements and developments through close contact with electrical and hydraulic suppliers. Salary open. Location, northern Illinois. Y7984.

Welding Engineer, M.S. Met., M.E. or E.E., up to 35 years of age. Prefer two years' experience in welding research work but may consider qualified recent graduate. Must know ferrous metals and welding procedures. Work will be on research of welding projects for oil refinery. Salary, $5520 to $7200 a year. Location, Chicago. R9479(a).

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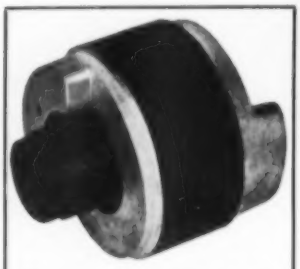

Close-up of die-cast aluminum rotor which is pressed onto the compressor shaft extension used in refrigeration units.

Our electrical industry produces fractional horse power motors at the rate of 20 to 25 millions per year. After World War II the leading manufacturers changed from fabricated copper rotors to cast aluminum rotors. In this operation, aluminum of high purity under closely controlled temperature is required.

In many cases the machines had to be placed right on the assembly line, with severe space restrictions and, of course, rigid requirements for reliability. AJAX induction furnaces and AJAX automatic pouring units were selected for this job in almost all the plants which switched from copper to aluminum rotors.

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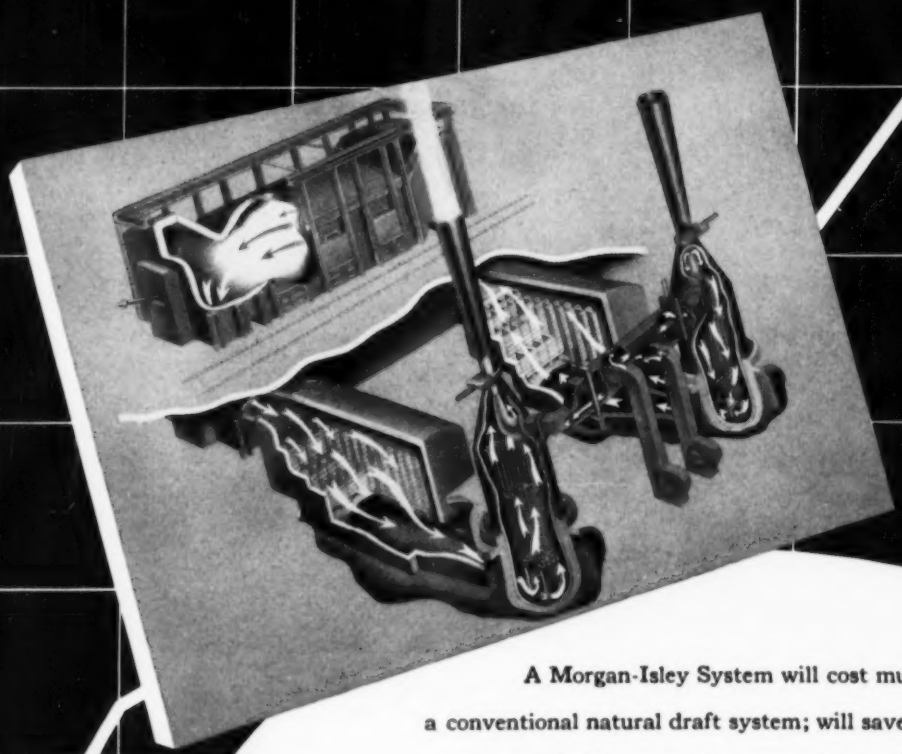

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Timken Company metallurgists achieve high accuracy with GE XRD-3 x-ray diffractometer

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1—BUTTERFLY VALVES: Butterfly valves designed to regulate the flow of air, gas, liquids or steam in conjunction with indicating, recording, or non-indicating pneumatic controllers are available from *Minneapolis-Honeywell Regulator Co.*

2—RESIN: A new resin that eliminates clay balls from foundry sand and makes possible the production of better castings was announced by *Monsanto Chemical Co.* In tests, Lustrex 886 has upgraded castings of steel, malleable iron, gray iron, phosphor bronze, aluminum and magnesium.

3—PLATING BARREL: A completely submerged plating barrel has been announced by *Hanson-Van Winkle-Munning Co.* The barrel is hexagonal in shape and has an ID of 14 in. Barrels are available in 30 and 36 in. lengths, having approximate capacities of 125 and 150 lb respectively.

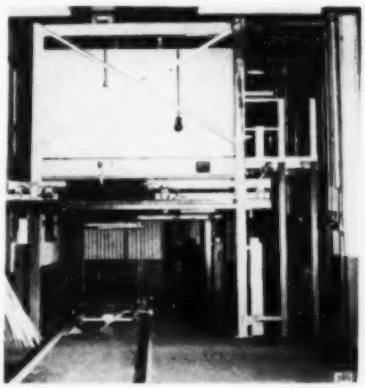
4—CLEANING SPRAY: Applied by a hand sized pressure spray *Kelite* spray white removes grease, oil, wax, light carbon, etc. It can be used on all metals, plastics, rubber,

concrete, wood, or porcelain. It accomplishes rapid cleaning without heat, odor, fumes, solvents, fire hazard, or danger to skin.

5—IMPACT PRESS: Speed of the press offers up to 10,000 strokes per hr. It also can be regulated to give proper ram action required for branding or color leaf marking. *Cadillac Stamp Co.*

6—FLO-METERS: A new line of flo-meters for indication of flow rates of air and industrial gases is available from *Waukee Engineering Co.* Available in 11 sizes, each meter has its own built-in calibration for the specific gas and rate of flow to be measured. They are designed for panel mounting, thus installation costs are minimized because piping can be simpler.

7—HEAT TREATING: Quick quench aluminum solution heat treating furnace that maintains a

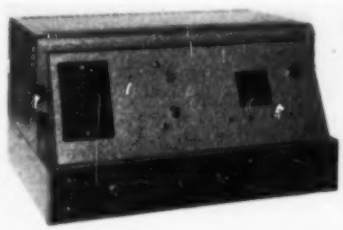


temperature uniformity within ±50°F and has a temperature range up to 1000°F. It quenches within 8 sec and has air operated doors and electric hoist that are interlocked. It has capacity up to 1000 lb. *Lanly Co.*

8—LINK SUPPORTED WALL: The *Geo. P. Reintjes Co.* link supported wall is designed so that the weight of each unit of refractories is transferred to the metal links. This eliminates refractories in tension, permitting use of lightweight refractories, silica refractories, acid brick tiles, or high alumina refractories as required.

9—GOGGLES: Non-toxic, heat resistant, and perspiration proof vinyl binding on side shields, eye binders, and bridges has been incorporated in new goggles to be worn on jobs where there is extreme heat. *American Optical Co.*

10—INTEGRATOR: Automatic electromechanical unit based on standard computor techniques provides



accurate time integral of any dc input function. *Instron Engineering Corp.*

11—MINERALIGHT: A high-intensity, longwave Mineralight designed for use as a portable black light inspection lamp has been announced by *Ultra-Violet Products, Inc.* It is an intense 100 w longwave ultraviolet hand lamp operating on 110 v ac, and throws a directional beam of longwave (3660 A.U.) ultra-violet up to 30 ft away.

12—FIRE FIGHTING: A one man fire fighting wheeled engine has been announced by *American-LaFrance-Foamite Corp.* It is a dry chemical with a capacity of 150 lb. The model weighs 480 lb fully charged and can be operated by one man. It is approved for extinguishing large scale B and C fires.

13—OXIDE COMPOSITIONS: A series of aluminum oxide compositions for the coloring operation in the finishing of zinc base and aluminum die castings have been introduced by *Hanson-Van Winkle-Munning Co.* The compositions may also be used in steel and stainless steel finishing.

Free Literature

20—ATOMIC CHART: Nearly 1300 different kinds of atoms now known to exist are shown in a new chart distributed by *General Electric Co.* The chart is arranged in checkerboard form, with a square for each nuclide or kind of atom. Mass, abundance, and other technical data concerning the nuclide are given in the various quares.

21—SPECIMEN POLISHING: Four-page folder describes the advantages of diamond abrasives for polishing metallurgical specimens. Diamet-Hypres is offered in three different particle sizes, all in 5 and 18 g gun applicators. *Buehler Ltd.*

22—CHILLING MACHINES: Brochure on Sub-Zero chilling for alloy steel heat treatment, metal stabilization, and gas dehydration has been published by *Sub-Zero Products Corp.* Specific treatment and heat-cold cycles for Sub-Zero transformation of austenite to martensite are given for water and oil hardening tool steel, alloy carburizing steels, high alloy die steels and high speed and moly type steels.

23—RESEARCH: Development and research at *Denver Equipment Co.'s* testing laboratories of various equipment are given in bulletin G3-B39. Ore dressing, ceramics, non-metallics, reclamation, etc. are a few of the fields covered.

24—VALVES: Catalog covering a series of valves for use where ammonia and other gases, noncorrosive to steel, are used is obtainable from *Henry Valve Co.*

25—SWEEPER: Dual brushes arranged in tandem and operating in opposite directions provide an entirely new sweeping principle. Described in catalog issued by *Moto-Mower Co.*, this sweeper is adaptable to both large and small areas.

26—CASTINGS: Castings produced in sizes up to 20,000 lb and available in chilled gray iron, alloyed iron, bronze and alloyed bronze are illustrated in bulletin published by *McLanahan & Stone Corp.* Information on facilities, location, and type of castings made is also included.

27—MATERIALS HANDLING: Materials handling equipment available from *Kornylak Engineering Corp.* is illustrated on a handy reference chart. The equipment is classified into categories of package handling, bulk handling, cranes and hoists, and several others.

28—CU AND BRASS PRODUCTS: A file size bulletin listing nearly 70 catalogs and technical handbooks on copper and brass products is available from *Chase Brass & Copper Co.*

29—ANALYZERS: Bulletin 148 BP contains information about Cambridge dissolved oxygen and dissolved hydrogen analyzers for steam generating plants. *Cambridge Instrument Co., Inc.*

30—METALLOGRAPHIC POLISHING: All of the popular Buehler two-speed polishers are described in this booklet. Units are available for flush or table mounting and in single, double, or triple unit tables. *Buehler, Ltd.*

31—CASTING SERVICE: Brochure describing ferrous casting services is available from *Detroit Gray Iron Foundry Co.* Illustrations show operations at the firm's three plants. Tables showing physical properties and chemical range of standard alloyed cast iron are included.

32—SPECTROSCOPIC ELECTRODES: Pamphlet available from *National Carbon Co.* lists important references dealing with the use of the various types of preformed spectroscopic electrodes. These electrodes are shipped in high purity packages to insure the manufactured purity of the electrode after leaving the factory.

33—STEEL PIPE: One of the alloy tubing steels widely used in elevated temperature service is discussed in a new technical data card issued by *Babcock & Wilcox Co.* It is particularly resistant to corrosion from hydrogen sulphide, elementary sulphur, and organic sulphur compounds.

34—HARDENING FURNACES: Gas fired, batch type hardening furnaces are featured in a new bulletin released by *Surface Combustion Corp.* Direct fired, horizontal hearth types and circular and rectangular salt pot types are included. Also shown is a complete line of controlled atmosphere equipment for hardening.

35—PLATE MAGNETS: Permanent nonelectric model C plate magnets are discussed in bulletin B-603 issued by *Eriez Mfg. Co.* The magnets incorporate stainless steel cap plates that insulate the pole plates and assure added protection against abrasion.

36—METALS' COMPOSITIONS: A metals chart showing the compositions of all commonly used metals and alloys in industry has been prepared by *Sam Tour & Co., Inc.* Constituent elements and percentage composition ranges for 60 different classes of metals are arranged in various groupings.

37—TEMPERATURE CONTROL: Manual titled *Design and Process Engineers Guide to Industrial Temperature Measurement and Control* has been published by *Partlow Corp.*

38—PLASTIMENT: Theory and practice of obtaining a good concrete is the subject of a booklet published by *Sika Chemical Corp.* Beginning with the gel mechanics of cement-water reactions, the booklet discusses factors affecting cement hydration and basic quality of concrete and how these factors can be controlled to reduce cracking and increase concrete hardness and impermeability.

39—CALROD HEATING: 1953 edition of *General Electric Co.'s* catalog on Calrod electric heaters and heating devices is available. Indexed by process and application, the catalog contains methods of determining power requirements and heat losses by applications. Graphs and formulas are also included. An index of GE application bulletins, and data and specification sheets available are one of the features of the catalog.

40—REPAIR WELDING: New manual designed as an aid to economical salvage of truck and car equipment is available from *Eutectic Welding Alloys Corp.* Photographs, diagrams, and charts illustrate quick ways to add years of service life to any automotive vehicle.

41—FORMBRITE: Physical properties, information on pressroom and finishing room procedures are included in booklet by *American Brass Co.* Formbrite is said to be stronger, harder, and springier than the usual drawing brasses, yet retains remarkable ductility for forming and drawing. It takes sharp, clean-cut ornamental die impressions.

42—PERSULFATES: Bibliography of properties and uses are presented in bulletin available from *Buffalo Electro-Chemical Co., Inc.* Approximately 100 references are cited.

43—BELT CONVEYOR: A pre-engineered, permanently mounted, power driver, reversible direction belt conveyor for inclined or horizontal operation is described in bulletin. Sketches show recommended installation procedures. *Rapids-Standard Co., Inc.*

Journal of Metals **April**
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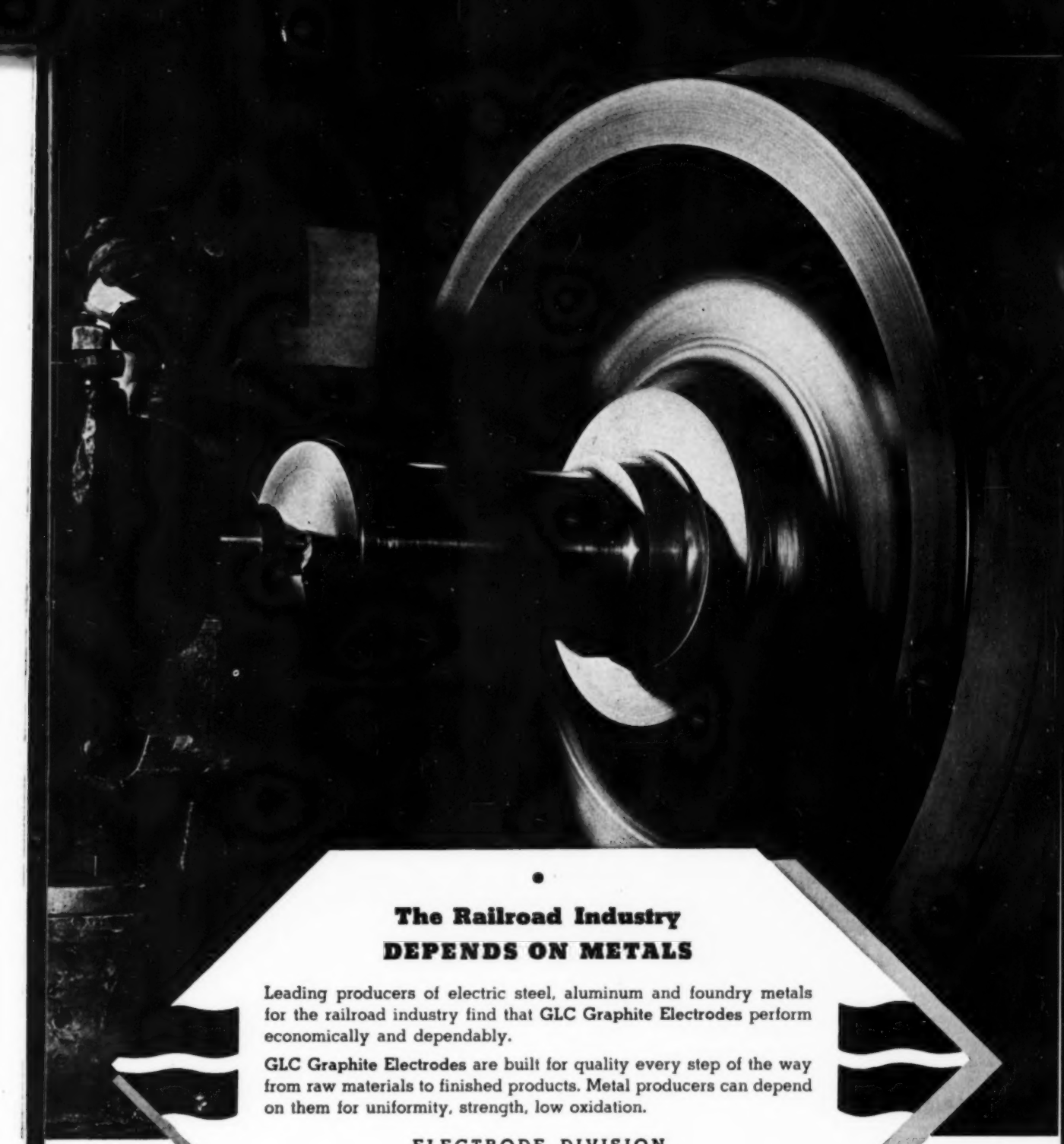

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GENERAL

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As the iron becomes steel, it is again cradled within walls of refractory brick. In the open hearth, advanced methods of refractory production have made possible major savings and increased output through longer campaigns. Grefco's modern research laboratories have contributed much to each step forward in open hearth refractory practice.

STEELKLAD basic brick is favored in specifications for end walls and side walls because of its resistance to spalling, low thermal conductivity, high hot strength and accuracy to specified dimensions. STEELKLAD-40 is increasingly popular in alternate rings with silica brick for zebra roof construction, providing a roof section that offers greater furnace availability.

As in its service to blast furnace men, Grefco is proud to join with other major refractories producers in serving open hearth operators, and—in turn, to provide industry with a *complete refractories service.*

GENERAL REFRACTORIES COMPANY, PHILADELPHIA

REFRACTORIES

ENGINEERS

OPPORTUNITIES

WITH

SYLVANIA

Where Product Development Is The Key To Continuing Growth

Product development has always played a major role in Sylvania's operations and is largely responsible for the company's growth to 40 plants throughout the nation. Similarly, Sylvania's Electronics Division is continuing its expansion program to accommodate increased development engineeering and manufacturing activities.

To engineers this means increasing opportunity with this 51 year old leader in the important field of electronics. At the Electronics plants in Woburn, Newton and Ipswich, Massachusetts you will enjoy the unique advantages of small plant operations in suburban areas minutes from the cultural and social activities of Boston. And — with Sylvania's assistance, you may continue your graduate studies at near-by world-famous universities.

Positions available for engineers with the following backgrounds:

MICROWAVE — with graduate work or experience in microwave theory. Positions will involve applications, measurements, or design of electronic test equipment for semi-conductor devices.

MECHANICAL — with experience in the following fields: 1. Design of small parts, tools, and jigs and fixtures. 2. Design of automatic production equipment.

SOLID STATE PHYSICISTS — Ph.D. or equivalent in experience in physics with a specialty in solid states work preferred. Will study electrical and optical behavior of semi-conducting materials.

METALLURGISTS — advanced degree or experience required. Will work on metallurgical preparations of semi-conducting devices.

ELECTRONIC — with graduate work or experience in product or circuit design and development.

Send complete resume to:

Mr. Robert L. Koller

SYLVANIA ELECTRIC

Electronics Division

WOBURN, MASS.

Industrial Notes . .

• Rated annual capacity of Bethlehem Steel Co.'s Johnstown plant is expected to reach 2.2 million net tons in the next year. Several new products are also expected to enlarge the plant's market. Continuing expansion plans begun in 1950, a new ore bridge, new heating furnaces at the wheel plant, rebuilding of six more open hearths, and installation of modern nail making machines in the rod and wire mill are on the year's schedule. Contributing to the plant's capacity is the recently completed blooming mill expected to roll the full ingot production.

• *Union Carbide & Carbon Corp. spent approximately $151 million last year for new construction, according to the firm's annual report. The amount represented the largest spent in the company's history. More than $674 million has been spent since 1946 for new facilities, bringing total plant account to over a billion dollars for the first time. The firm spent $112 million in 1951. More than half the plant expenditures made since 1946 have been for plastics and chemicals, one third for alloys and metals and the remainder for industrial gases and carbon products. In 1952, $70 million was spent on plants for alloys and metals, $51 million for chemicals and plastics, $13 million for electrodes, carbon and batteries, and $15 million for industrial gases and carbide.*

• Sylvania Electric Products Inc. new facility at Hicksville, N. Y. is developing new types of materials for use in atomic reactors. The project aim is to develop materials enabling atomic reactors to operate at higher power levels, increasing their efficiencies. It would be important, for example, in operation of a nuclear reactor for production of electric power. Materials used in nuclear reactors must remain structurally sound at high temperatures and under intense atomic radiation bombardment. They must not soak up neutrons needed to continue the atomic chain reaction or to produce plutonium.

• **U. S. Steel Co. claims the largest continuous rubber and fabric conveyor belt operates between the coking plant and blast furnaces at its Fairless works in Morrisville, Pa. The Goodyear Rubber & Tire Co. belt measures 5500 ft from the center of the head pulley to the center of the tail pulley. Cost is estimated at $500,000. Coke weighing 30 lb per ft and at approximately 250°F is moved at 300 ft per min at a capacity rate of 400 tons per hr. The 11,000 ft of belt-**

ing is 4 ft wide and is constructed of synthetic rubber and rayon.

• An agreement has been reached between Sintering Machinery Corp., Netcong, N. J. and Equipment Developing Co., Inc., Montclair, N. J. for development, manufacture and sale of a complete line of filtration equipment to be marketed under the trade name of Edco-Sintering. Sintering Machinery will manufacture and stock filtration units and parts. Equipment Developing will design, engineer, and sell the line. Complete developing and testing laboratories will be maintained.

• **A Government research project has made a report on magnesium castings using the shell molding process. Because of its high chemical activity molten magnesium reacts with oxygen, moisture and sand. Scientists working for the Army Ordnance Corps investigated various materials which might act as inhibitors. Results of investigations are contained in** *PB 111049, The Application of Shell Molding to the Production of Magnesium Castings.* **Address Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.**

• No. 1 blast furnace at U. S. Steel Co.'s Duquesne works has been put back into operation. The furnace was taken out of service last December 15 for complete relining, including the hearth, bosh, and stack. Hearth diameter was increased from 19 to 20 ft and other alterations made. Iron making capacity was also increased from 635 tons a day to 704 tons daily. The furnace ran 2132 days during its last campaign making 1,402,643 net tons of iron.

• *Expansion of powder metallurgy parts production at American Brake Shoe Co.'s Hillburn, N. Y. plant is expected to double present capacity. The plant is operated as a unit of the American Brakeblok div. that manufactures automotive and industrial brake lining and laminated plastic bearing materials. The company entered the powder metallurgy parts field after four years of experimentation. First products to be marketed were friction materials for clutch parts.*

• Primary aluminum production in 1952 hit an all time high with 937,321 tons, 17,000 tons above the previous record established in 1943. Production was 12 pct greater than that of 1951 when 836,879 tons were produced. Final month's production was 83,409 tons, or 11,000 tons more than December 1951.

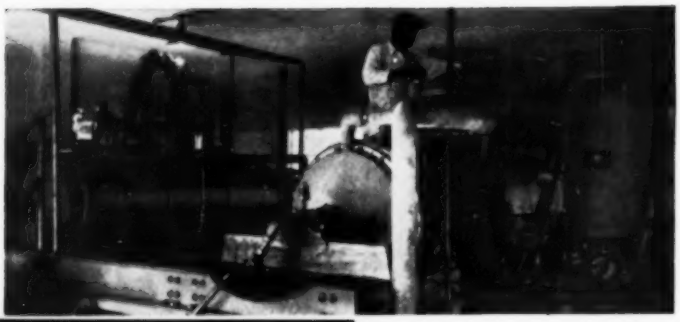
fast *
sure *
safe *

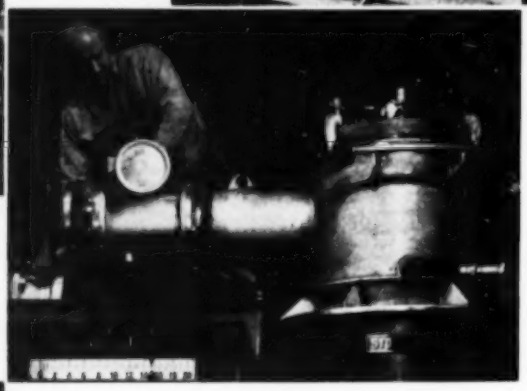
* three ways to describe Salem-Brosius clay guns in operation at the blast furnace tap hole. For more than three decades our engineers have diligently applied their experience to the design and production of efficient low-cost guns. That's why so many Salem-Brosius guns have been working so long—so well. Available mechanical, hydraulic, or steam—pedestal or column mounted. For fast, sure, safe guns—please write to us.

SALEM-BROSIUS, INC.

Sales and Executive Offices
[illegible] Fourth Avenue, Pittsburgh 22, Pa.

Operator removes boxes of tubular paper capacitors from Stokes Vacuum Impregnator at Pyramid Electric Co., North Bergen, N. J. Capacitors have been impregnated with mineral oil to improve stability and lengthen service life.





Installation of Stokes Rotary Vacuum Dryers used by Metals Disintegrating Co., Berkeley, California, for drying of aluminum powder. Highly oxidizable materials can be handled without any danger of combustion or explosion when processed in vacuum.

Operator transfers evacuated retort from heating to cooling station of Stokes Vacuum Annealing Furnace, built for processing, annealing and other heat treatment of titanium, zirconium, hafnium and copper.

Operator loads shell-frozen human blood plasma into one of the Stokes drying chambers of the lyophilizing plant at the Sharp & Dohme, Inc. biological laboratories, Glenolden, Pennsylvania.

There is no romancing about Vacuum at Stokes!

Vacuum processing starts with a vacuum-tight system and pumps to exhaust the air.

These are simple truths, the significance of which is never forgotten among men who have worked for many years in vacuum engineering.

Stokes men have many years of *engineering* experience, *shop* experience, *operating* experience in the design, construction and installation of vacuum processing systems.

But the absence of romancing in Stokes' thinking implies no want of imagination! Indeed, the practical application of vacuum processing—which gives us blood plasma, the "wonder drugs", costume jewelry, diesel locomotive motors, radio and electronic communication—had much of its inception in Stokes laboratories; takes practical shape in Stokes vacuum processing equipment for industry.

Stokes is FIRST in Vacuum . . . in great and small industrial plants, in schools, hospitals, and laboratories throughout the world.

F. J. STOKES MACHINE COMPANY, PHILADELPHIA 20, PA.

STOKES

STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages / Industrial Tabletting, Powder Metal and Plastics Molding Presses / Pharmaceutical Equipment

Corrosion Resistant Zirconium Metal Now available

(limited introductory quantities)

The extraordinary resistance of Zirconium Metal to nearly all forms of chemical attack offers many practical and advantageous applications. It compares with tantalum in acid resistance and surpasses tantalum in resistance to alkalies.

Present and promising applications are in the field of electronics, chemistry, aviation and surgical use among others.

Now offered in limited commercial quantities, Zirconium Metal can be machined, welded and cast. Write for literature giving physical, mechanical and chemical properties as well as supply and prices.

BARS

RODS

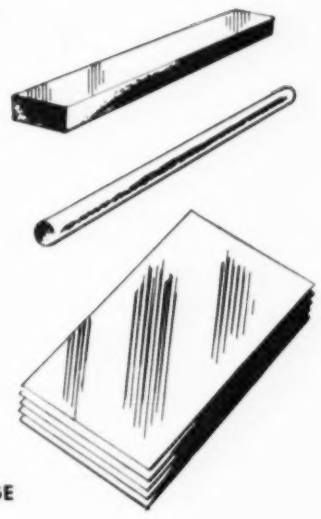
SHEET

WIRE

SPONGE

BRIQUETTES

TUBING

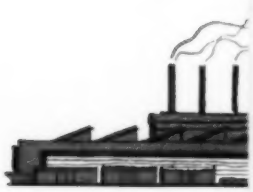


Zirconium Metals Corporation of America

A Subsidiary of National Lead Company

111 BROADWAY **NEW YORK 6, N. Y.**

in the field of refractories . . .



HARBISON-WALKER *Leadership*

These among other refractories pioneered by Harbison-Walker continue to make history in the metallurgical industries.

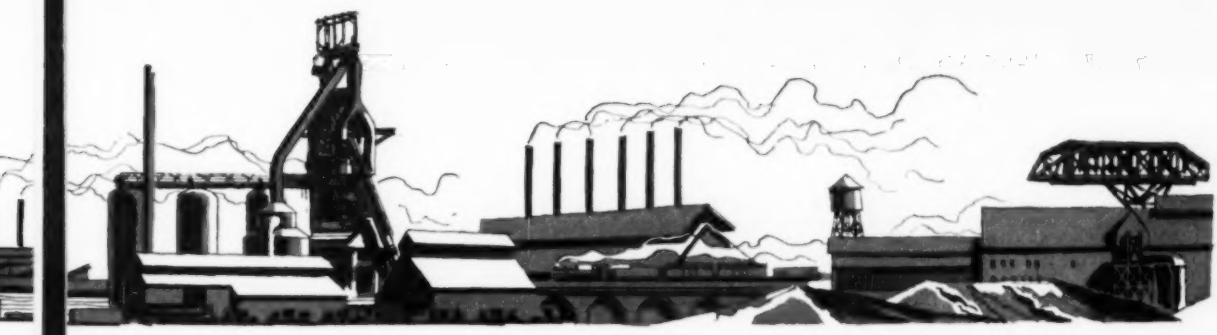
VACUUM POWER PRESSED BLAST FURNACE BRICK—This development by Harbison-Walker provides refractories with superior properties of uniformity, lower porosity and permeability, and increased strength. Various Harbison-Walker blast furnace brands are produced by this method.

H-W 18—A high-fired iron blast furnace refractory which was developed to meet a demand for maximum resistance to abrasion and to disintegration by carbon monoxide. This unusual high duty fireclay refractory meets the rigid standards of quality and uniformity in dimensions and workmanship. Its excellent properties account for the splendid service it is giving in complete blast furnace linings.

METALKASE—The steel-encased chemically-bonded basic refractory first introduced by Harbison-Walker many years ago has effected great economies in its extensive use in open-hearth and electric steel furnaces and in many other applications.

VEGA—The original super-duty silica refractory, VEGA, provides a margin of refractoriness which permits higher operating temperatures, renders longer service and reduces maintenance costs. In addition to its wide use in the steel industry, VEGA finds many other economical applications.

HARBISON-WALKER



IS BASED UPON *Solid Achievement*

Whatever your requirements for refractories may be, there are available Harbison-Walker products of highest quality for every application.

Over the years, a policy of continuous development and improvement has given Harbison-Walker a position of leadership based on achievement. For more than half a century, Harbison-Walker Blast Furnace Refractories have enjoyed a wide preference in the industry. Today, considerably more than half of all the blast furnaces in the United States, Canada and Mexico are lined with Harbison-Walker refractories. During the recent expansion of iron-making facilities, the choice has been Harbison-Walker linings for 17 of the 20 new blast furnaces, 14 of which are complete linings.

Harbison-Walker refractory products include all types and classes for blast furnace stoves, open-hearth and electric steel furnaces, by-product coke ovens, soaking pits and all the various metallurgical furnaces.

REFRACTORIES COMPANY

AND SUBSIDIARIES

World's Largest Producer of Refractories

General Offices: Pittsburgh 22, Pa.

ATOMIC energy has not been widely applied in the metalworking industries, although it is expected that some day application will bring tremendous benefits. A report issued by the Council for Technological Advancement states, "the indirect effect of the development of atomic energy is likely to be felt increasingly in the metalworking industries, and to have outstanding significance for United States technology overall."

At the moment however, one important roadblock exists. Unless the time comes when U. S. private industrial might is mobilized toward development and application of atomic energy there seems little likelihood of any tremendous surge of development for civilian use. "Maximum benefits will be attained only when private enterprise is able to participate in this technological advancement to the extent that it has in those of the past."

Perhaps the same kind of force which made the automotive, chemical and other giant industries what they are today is needed for atomic energy development. Today, only a few companies share in the work. As good a job as those firms are doing, much more is required if the full potential of atomic energy is to be realized.

The report breaks down the interest of private industry in future development into two categories: Production of electric power from heat derived from nuclear reaction; and industrial application of radioisotopes.

While use of radioactive tracers for example is not new, atomic piles have made such materials available in larger quantities. Use of this technique has resulted in cost savings and product improvements. One use of radioisotopes has been application of tracer techniques in the measurement of wear in cutting tools. The idea was to cut costs in metal cutting and cutter preparation. Conventional tests involve running the machine for many hours. Test costs can be reduced by using radioactive tools and a Geiger counter to measure the amount of metal worn from the cutting tool. Metal worn from the cutting tool adheres to the chips (about 95 pct of the worn metal adheres) and because it is radioactive can be measured with the Geiger counter. Less metal adhering to the chips—the longer the life of the cutting tool.

Radioactive tracers have also been used to determine the amount of wear in engines using different lubricants. The usual method is to weigh engine parts before using. After a fixed running time, parts are reweighed and the difference in weight indicates amount of wear. Under the tracer method piston rings are exposed to radioactive rays at the Oak Ridge atomic pile. After running the engine for the same period oil is drained and measured for radioactivity. Extent of wear of piston rings is proportional to the radioactivity of the oil.

Use of radioactive materials in automatic control of metallurgical processes is still in its infancy but progress is being made. Instruments to detect and measure radiation from high energy X-ray and radioactive sources are commercially available. They can be used to measure thickness of material, package density, and liquid levels. Connected with proper servomechanisms, these instruments can be used for automatic process control.

Fission products, radioactive byproducts of the fission process are significant for the potential availability as a source of large-scale low cost radiation. Employed in radiographic techniques, they are useful for industrial inspection of metals.

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ALUMINUM Co. of America research men are looking for something to do with gallium. The minor metal has properties that make it almost a shame not to find some kind of application for it. Right now, however, gallium costs $1000 per lb, which is something of a drawback. It melts at approximately 86°F but doesn't boil until 3600°F or higher. It expands upon solidification. Gallium shows marked differences in electrical resistivity and coefficient of thermal expansion along the direction of the three axes of its crystallographic structure. Its resistivity variability is believed greater than any other metal. It emits electrons at extremely low temperatures. Combine all those properties and gallium is obviously a unique metal.

Some uses for the metal exist. It is used in dental alloys for gold restoration work. A patent has been issued for minor use in selenium rectifiers. Its most promising use, however, is a liquid seal on the inlet system of mass spectrometers, where its liquid range and low vapor pressure make it superior to mercury in analyzing hydrocarbons with high boiling points.

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STEEL mill electrification made significant strides during the past year with much increased capacity traceable to an additional 169,000 hp in large mill motors and 138,000 kw in motor-generator sets supplied by the General Electric Co. to the steel industry. Much of the equipment was used for main mill drives and was supplemented by additional thousands of horsepower and kilowatts of auxiliary motors and motor-generator sets.

The electrical industry's contribution to the steel industry led to higher speeds and an increased amount of automatic control for mill operations. Among the installations which substantiate this viewpoint is a new five-stand tandem cold reduction mill placed in operation during 1952 capable of rolling tin plate at a rate of 7000 fpm. Top rated speed for cold strip mills in 1933 was 800 fpm.

A West Coast steel mill can now claim the fastest vertical acid type electrolytic tinning line in the world, with a rating of 1200 fpm. The operation produces 10 two-ft long sheets of tinned steel per sec. The entire process consists of plating, reflowing, oiling, shearing, classifying, and piling of tin coated steel strip. In addition design of the feedback con-

trol system aided advancement of analysis methods. Calculating machines and electronic computators predetermine the transient performance of all types of automatic control systems.

General Electric also introduced an electronic steel mill width gage, a noncontacting device which continually and automatically monitors the width of hot strip steel to an accuracy of one eighth in. Magnetic amplifiers and other new tools have found wider application. The transistor promises present day electronic system performance with the ruggedness and reliability of current amplifier and amplidyne systems.

Pumpless mercury arc rectifiers continue to gain in popularity as an economic means of converting alternating current to direct current. Pumpless equipment is employed for main drive power as well as for constant potential supply in the steel industry.

W. E. Miller, General Electric manager of steel mill engineering notes that blooming mills have increased productivity by modernizing main and auxiliary drives. Modern amplidyne controls have been adopted for main drives by more than 60 mills, according to Mr. Miller. He also points out that the trend on dc bus systems for hot strip mills is to split the bus into sections. The advantages lie in reduced short circuit stresses and increased flexibility in speed cone and rolling schedules. Mr. Miller reports that a six-stand finishing train and with completely sectionalized bus was put into service in 1952 with each mill stand receiving power from its own individual generator.

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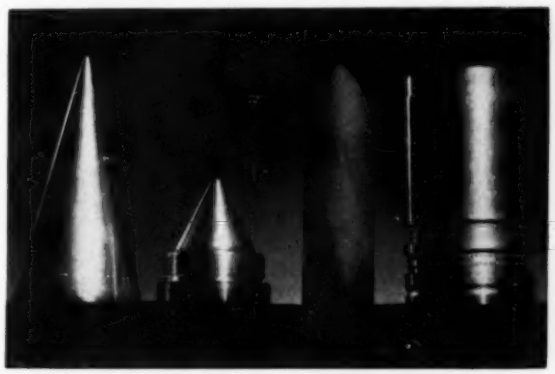
POSSIBLY one of the more dramatic incidents in World War II took place during July 1944, when the Allied spearhead in Europe felt the effect of the German Tiger tank at St. Lo. The Tiger was one of the most devastating armored vehicles introduced into the war and nothing the Allies had would stop it. The Tiger's armor was fantastically thick and anti-tank shells failed to penetrate. General Eisenhower flashed word to Army Ordnance in the U. S. on D plus 30, that an anti-tank shell had to be developed to stop the Tiger or the Allied invasion would be seriously slowed or even halted.

Detroit Ordnance district had been working with Carboloy Dept. of General Electric Co. in turning out huge quantities of cutting tools made of tungsten carbide. Development work on anti-tank shells had been done with tungsten carbide but initial trials were far from complete. Within two days, ten cores were produced ready for test firing at Aberdeen Proving Grounds. In normal times delivery might have taken years. On July 13, Aberdeen reported:

"The answer to the German Tiger has been found —firing at even a 20° angle these Carboloy cores would penetrate the thickest armor."

That night information on mass production of the core was gathered. Plant capacity was nonexistent. Tungsten carbide was already being produced at peak production capacity and equipment to make anti-tank shells was working overtime elsewhere. Yet, production started. A grinder was flown from Connecticut. Twenty tons of steel was cleared by hand from a storing shed in three days—a job normally taking 3 weeks. Two machines bound for the



Relation of tungsten carbide core to the anti-tank shell is shown by the exploded view. From left to right are the windshield, nose piece, core, and body, less rotating bands. Kayo punch against the tiger was the tungsten carbide core. Shell was produced in record time during World War II and is now in use on the Korean front.

Orient were taken off a San Francisco dock. A Detroit manufacturer built a special sintering furnace in 19 hr. The furnace needed hydrogen—and this was found in Ohio. The Navy supplied trucks from one of their Texas bases to move the hydrogen to Detroit. Production started in less than 2 weeks. The same shell that stopped the Tiger is being used today by UN forces in Korea.

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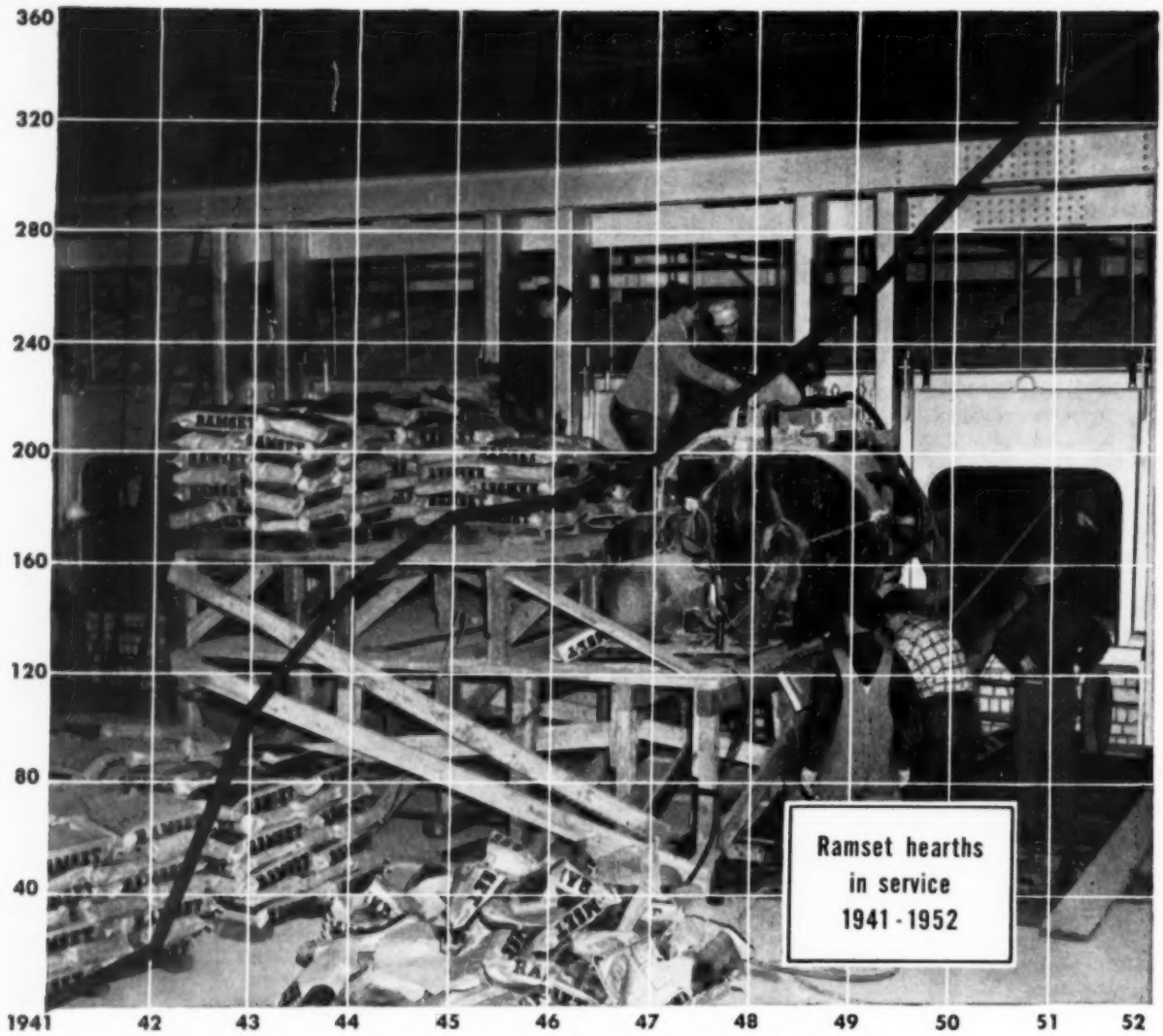
AN estimated 97.6 million gross tons of iron ore were produced in 1952, considerably less than the 116.5 million gross tons produced during the previous year. The steel strike which extended to mining operations gets most of the blame for the flagging production figure. The situation might have been much more discouraging if not for the monumental effort put forth by Lake shipping facilities following the strike. Enough ore was transported to supply steel mills through the winter months, thus negating the necessity of all-rail shipments during the period when the lakes would be closed. November lake shipments were 63 pct higher in 1952 than in the same period the year before.

Producing districts showed slight change in percentage distribution in 1952, with the Lake Superior region accounting for 79.2 pct of production—compared with 80.6 pct in 1951 for the only marked change. Other areas made slight advances.



for open hearth bottoms it's Ramset 2 to 1

A MAJORITY of the hearths installed in the new open hearth shops that have been placed in operation over the past several years are of rammed construction. In the new shops using this construction, Ramset installations hold a 2 to 1 advantage over any other magnesia ramming mix.

Basic Refractories pioneered the development of rammed hearth methods. These methods have been continually refined over the intervening years by the practical steelmakers who make up Basic sales and service staff. A few years ago Basic supplemented this advanced technique by making available mixing, conveying and compacting equipment specifically designed for the job.

Thus in selecting Ramset for a hearth installation the steelmaker avails himself of a proven refractory, the most modern of installation methods and equipment as well as the services of Basic personnel who, by background and training, are skilled in the use of granular basic refractories.

GRANULAR BASIC

REFRACTORIES

Basic Refractories Incorporated • 845 HANNA BUILDING, CLEVELAND 15, OHIO

Exclusive Agents in Canada: REFRACTORIES ENGINEERING AND SUPPLIES, LTD., Hamilton and Montreal

Drift of Things

AMONG electrical manufacturers, interest in the outlook for copper supplies has not diminished despite signs of a healthier market following price decontrol. Reason: Electrical utility industry output is expected to grow at an average annual rate of 6 pct for the next 15 years. A more graphic description of the growth ahead is given in the Eighth Quarterly Report of the Director of Defense Mobilization as follows: "Power generating capability, which amounted to 63 million kw at the time of Korea, now stands at more than 81 million. The established goal for installed capability at the end of 1955 is 116 million kw. Orders already on the books of power equipment manufacturers, if fulfilled on schedule, will bring installed capability to over 123 million kw by the end of 1956—and more orders for equipment are yet to come."

These statistics portend an impressive requirement for copper, not only for power plants and distribution lines themselves but for the multitude of industry and domestic end-uses.

What of copper supplies to meet this heavy expansion? Supposing a free market for the red metal, it is safe to say that there will be more copper available from both domestic and foreign sources. However, the needs of consumers will probably exceed supplies resulting in a greater consumption of such substitute materials as aluminum.

S. W. Anderson, former deputy administrator for aluminum, DPA, stated in an article in JOURNAL OF METALS, March 1953, that the electrical industry is using extensive quantities of aluminum. It has gained particular acceptance in high tension transmission lines because of its light weight. It is also being used for lamp bases, covered wire, bus bar and smaller sizes of wire used for communication wire, and motor and transformer windings. Stating it another way, the percentage of copper used per kilowatt capacity in 1960 will, we think, be lower than it is now; the converse being true for aluminum.

Two corollary thoughts occur for those shaping future plans. One is in product development. Aluminum, although lighter than copper has a lower current-carrying capacity than copper. This means bigger units and structural parts must be heavier resulting in a heavier over-all weight per machine per kilowatt capacity as compared with copper machines. What the electrical industry wants is a better current conductor, better than copper.

The other is in business diversification. Anaconda Copper Mining Co., fully integrated in copper, has gone into the aluminum business. What copper this company does not have to sell, it can make up in aluminum. This lead deserves consideration by other mining companies whose main source of income is limited by either resources or markets.

MARKET research has always been a nebulous sounding business to us but since a recent interview with a practitioner we've taken to shaking our head with that the-patient's-condition-is-serious-look when corporation executives reply in the negative to our query as to whether they have such services. This particular gentleman was shaping the destiny of a steel corporation, the identity of which we cannot disclose.

Standard operating equipment for the market researcher or statistician, as they are sometimes called, is two offices with ample desk space, one for a battery of secretaries and/or clerks and the other for himself. Long roll statistical typewriters and computers are also essential. We are of the opinion that the researcher should preferably be a good talker, diligent in the presentation of data, and of effervescent personality. The one we interviewed fitted this pattern and, indeed, gave us a free course on business trends—past and present.

Empire building is all in the day's work for the good market researcher. This calls for spending some of the corporation money or better still borrowing some. This is achieved by studies of business, consumer, population, and industry trends. Can your company expand, merge, buy out, or add a new plant here or there to open a new market or increase services to present customers by product diversification? The good statistician is in and out of Washington, travels the country here and there probing the sinews of economic structure. Once an exploitable area is found he must go into his sales act to drum up interest of the directors. This calls for showmanship—mock ups, graphs, movies, and speeches are all part of the act.

For sales development the researcher is invaluable. When the salesmen are feeling low because business is down, the present-day market researcher can pull out graphs and charts to prove that with expanding population, increased steel capacity, defense considerations and the like, plus a rising trend line since 1939; business must be good because it can't be anything else. If this argument is well bolstered with statistics, salesmen usually begin to feel better (which is half the battle). The follow-through is to pull out a sheaf of prospective customers in embryo industries which have not hitherto been exploited. With a pat on the back new sales energy is unleashed.

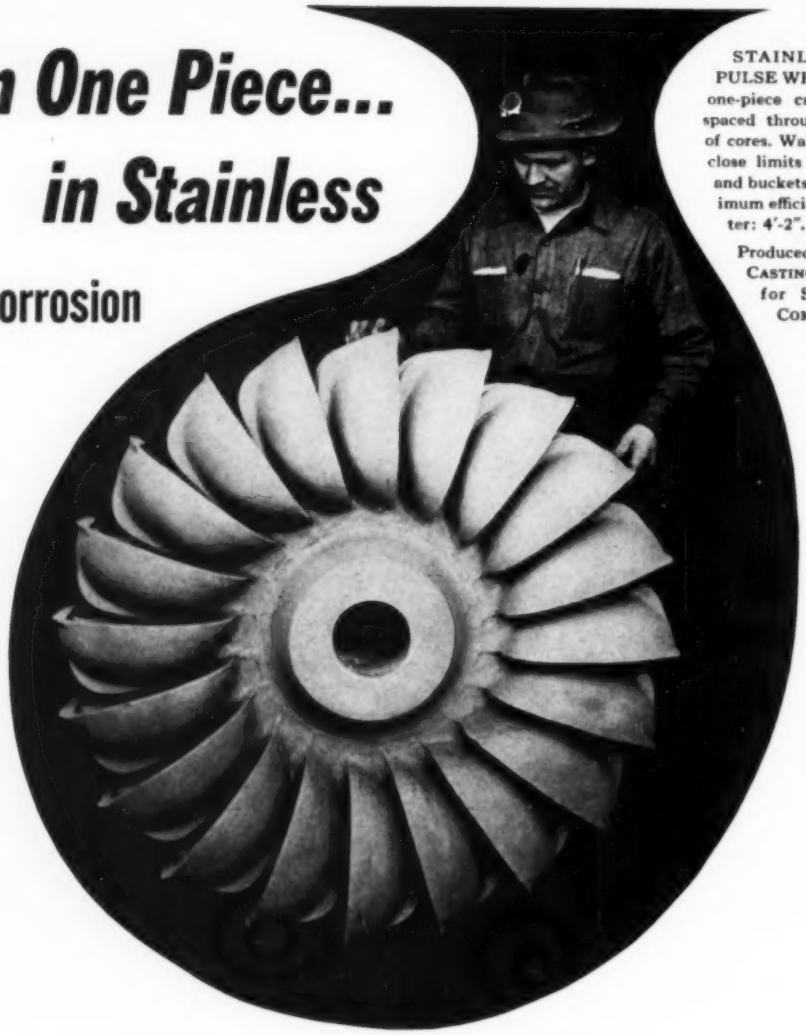
These activities require a certain indomitability, resilence, or what have you, as the market researcher often gets slapped down. They are back there pitching the next day though. Any corporation without a good market researcher is dead on its tail.

A PROMINENT corporation director was traveling on a train where he was greatly impressed by the sales ability of an aggressive Union News Co. boy who managed to sell him something every time he came through the car. The director was so impressed he informed the home office to hire this man and put him on the sales force immediately. A reluctant officer put the young salesman to selling coal as he thought he would get into the least amount of trouble in this department. In those days the corporation did not have a training program and the energetic youth made his first sales call with practically no training. The customer's first question was "now what about the Btu's in your coal." Our hero hitched his chair up to the table and waggling a finger at the customer, he said "that's one thing you can't say about our product, we screen them out at the mine."

John V. Beall

Cast in One Piece... in Stainless

to resist corrosion



STAINLESS STEEL IMPULSE WHEEL. Buckets in this one-piece casting are accurately spaced through proper alignment of cores. Wall sections are held to close limits to maintain balance, and buckets are polished for maximum efficiency of wheel. Diameter: 4'-2". Weight: 2200#.

Produced by EMPIRE STEEL CASTINGS, INC., Reading, Pa., for S. MORGAN SMITH COMPANY, York, Pa.

Corrosion meets its master in this impulse wheel of cast austenitic stainless steel containing 19 percent chromium and 9 percent nickel...

Furthermore...in hydroelectric power generation, under the terrific impact of a "high head" of falling water...this *stainless* casting tends to work harden while putting water to work, thereby improving its resistance to erosion and abrasion.

Impulse wheels are only one of countless applications in which advantage may be taken of the various useful properties of chromium-nickel stainless steels.

You can trim bulk and deadweight by specifying correct types of stainless. Strong and tough, stainless steels resist wear and attack by nearly all oxidizing acid conditions. Moreover, complexity of design is not a limiting factor in casting chromium-nickel stainless.

Austenitic stainless steels resist creep, scaling and oxidation at elevated temperatures. And at sub-zero temperatures, they offer exceptional resistance to impact.

Investigate all the economies you may obtain by using stainless steel equipment. Send us your inquiries on the use of cast or wrought stainless alloy steels. Write us details of your problems for our suggestions.

At the present time, nickel is available for end uses in defense and defense supporting industries. The remainder of the supply is available for some civilian applications and governmental stockpiling.

INCO

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Kaiser Steel Co.'s two blast furnaces at the Fontana works produced a daily average of 1335 tons of pig iron during 1952, while being rated at only 1200 tons per day. The furnaces consumed an average of 1409 lb of coke per net ton of iron produced, compared to a national average of 1600 to 1700 lb per ton. A detailed account of the Fontana blast furnace operation appears as a JOURNAL OF METALS feature in this issue.

Youngstown Sheet & Tube Co. sharply increased production at its Indiana Harbor works when it placed its new No. 3 blast furnace into operation. Hearth diameter of the furnace is 28 ft, with a rated capacity of 1500 tons per day. The unit is the third major installation since the Indiana Harbor expansion started in 1950. Last May the new open hearth dept. of eight 250-ton furnaces went into production. A new 75-oven coke battery was started up last fall. A blooming mill and a rolling mill are under construction.

Inland Steel Co.'s Steep Rock iron ore venture promises to be a huge undertaking with some $50 million to be spent in 7 years to bring the leased property into production. Inland has been involved in Canadian ore exploration for about 20 years, but the Steep Rock development marks the firm's first actual mining activity. Test drillings indicate that at least 50 million tons of ore exist on Inland's lease. Ore boats from Port Arthur will have 120 miles less to travel to Inland's Indiana Harbor iron and steel facilities than on the trip from the Mesabi Range. Three million tons of ore will be shipped annually when the mine is in production.

Pilot plant tests conducted by the Bureau of Mines and the American Iron & Steel Institute indicate that about half of the nation's manganese requirements can be supplied from open hearth slag. Mangaslag, Inc., recently signed a contract with Defense Materials Procurement Agency and will use the Bureau of Mines process to produce 1000 tons of ferromanganese monthly. Further details are contained in this month's JOURNAL OF METALS feature section.

A new corrosion resistant alloy has been developed by Haynes Stellite Co., div., Union Carbide & Carbon Corp. The nickel, molybdenum, chromium, iron alloy can be used to handle both acid and alkaline solutions, and will resist pitting and stress corrosion cracking in chloride solutions. The new alloy is called hastelloy alloy F and as yet has not been fully tested.

Cobalt supply situation vastly improved during 1952, according to the Bureau of Mines. Free world production is estimated at 10,000 metric tons compared with 8500 tons in 1951. The total picture improved, it is believed, because of larger use of scrap. U. S. consumption reached a record 10,786,713 lb in 1952.

Portugal plans to establish an iron and steel industry of its own using the nation's large iron ore reserves. Portugal imports about 200,000 tons of pig iron and rolled products, a situation which contributes heavily to the country's foreign trade deficit. Under the Government's economic development plan for the next six years, some 250 million escudos are to be invested in iron and steel production.

Iron powder metal parts, made of steel oilite, developed by the Amplex div. of Chrysler Corp. are said to have several times the ductility of previous iron powder products. Physical properties of steel oilite are comparable to mild carbon steels such as SAE 1010, 1020, or 1030.

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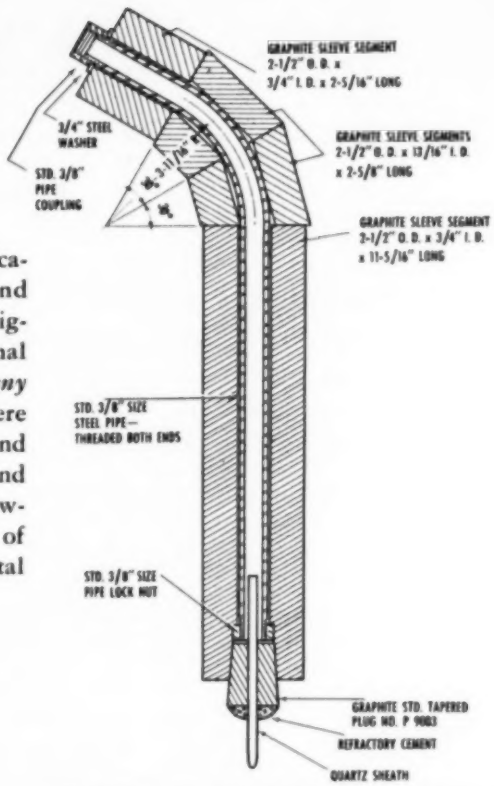
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National Open Hearth Steel Committee

Local Section Activities

BUFFALO SECTION

Members of the Buffalo Section have been active in making arrangements for the National Open Hearth Meeting to be held in Buffalo April 20 to 22, 1953. H. L. Allen, Jr., has been Chairman of the Local Committee.

The Annual Meeting of the Buffalo Section was held Nov. 18, 1952. An inspection trip of No. 3 open hearth shop at the Lackawanna plant of Bethlehem Steel was made before the meeting. Following lunch, H. H. Northrup, Program Chairman, opened the discussion which covered *Promoting Safe Practice in the Open Hearth, Methods of Improving Charging Practice, Methods and Advantages of Bath Temperature Control, Open Hearth Practice Affecting Wire Manufacture, Variations in Practice to Increase Ingot to Product Yield,* and *Quality Effects of Steel Pouring.* R. H. Ferguson, A. I. Gorman, Norman Fennie, R. P. Cameron, R. D. Hindson, and T. B. Winkler led individual topics. National Chairman J. J. Golden and Secretary-Treasurer Ernest Kirkendall attended the cocktail hour and dinner. Total attendance at the meeting was 237 members and guests.

Officers for 1953 are:

A. K. Moore, Chairman; H. H. Northrup, Vice-Chairman; H. A. Morlock, Secretary-Treasurer; and John Fleming, L. B. Wright, Dean Young, W. Stewart, J. L. Walton, and H. L. Allen, Directors.

A. K. MOORE
Steel Co. of Canada, Hamilton, Ont.
Chairman, Buffalo Section

EASTERN SECTION

Activities of the Eastern Section during 1952 began with a plant visit at Sparrows Point. The registration of 196 men represented 14 steel companies and 24 suppliers. A business meeting followed lunch with appointment of officers for the Fall Meeting the primary purpose.

The Fall Meeting was held October 10 at the Warwick Hotel, Philadelphia with a record 271 registration. The morning session program consisted of: *Air Temperatures and Infiltration, Organizing for Maintenance of Temperatures and Checker Limitations,* and *Firing Methods.*

The afternoon portion of the program consisted of: *Recommendations for Handling Furnaces During and After Prolonged Shutdowns, Development at Fairless Works,* and *Scrap Preparation.*

Bylaws, which had been approved during the previous year, were presented and distributed to Directors. A plant visit is scheduled for May 22, 1953 to the Bethlehem plant, Bethlehem, Pa., to be followed by a meeting of the Directors and Executive Committees to appoint a committee for the Fall Meeting, set for October 9, at the Warwick Hotel. Rex M. Baker is Chairman of the Section.

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PITTSBURGH SECTION

Two events marked activities of the Pittsburgh Section during the past year. These were the golf party in June and the Off-the-Record meeting in November. The South Hills Country Club served as the backdrop for the June 3 golf party and despite the distraction of the steel strike, 89 members and guests of the Pittsburgh Section strode the fairways and were present at the dinner climaxing the day's events.

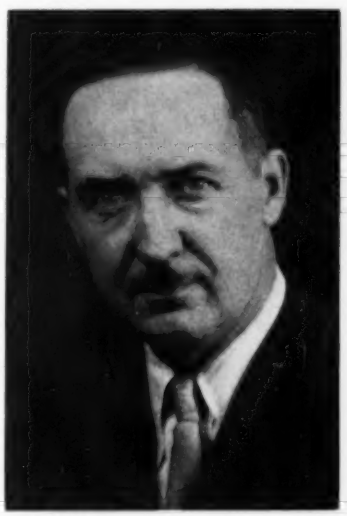
J. J. Golden, National Open Hearth Committee Chairman, served as toastmaster at the dinner in the absence of Pittsburgh Section Chairman J. F. Pollack who could not attend because of strike conditions. Party Committee was composed of H. M. Rich, R. W. Crozier, J. Isherwood, E. Sipp, and F. St. Vincent.

The Seventh Annual Off-the-Record meeting at the William Penn Hotel, Pittsburgh, was attended by 670 members and guests of the AIME. The meeting was a joint effort on the part of the Pittsburgh Section and the National Open Hearth Committee. G. R. Fitterer, University of Pittsburgh, and L. Thiessen, Vesuvius Crucible Co., served as Program Chairmen for other AIME Divisions holding sessions during the meeting. W. H. Mayo, L. W. Moore, W. S. Debenham, and A. R. Altman assisted Mr. Fitterer in arranging technical sessions on metallurgy, operations, refractories, and acid open hearth.

R. W. Crozier, Chairman, J. Isherwood, E. Sipp, and F. St. Vincent were the committee which arranged details for the supplier's cocktail party. Activities were concluded with a Fellowship Dinner attended by 284 members and guests of the AIME. G. J. Donaldson, Chairman of the Pittsburgh Section, AIME, served as toastmaster. Lew Worsham, Oakmont Country Club golf professional, gave an after dinner talk and golf clinic.

The Iron and Steel Div. Night program was presented at the Mellon Institute Auditorium, Pittsburgh, Mar. 2, 1953. The program was jointly arranged by the Pittsburgh Section and the National Open Hearth Committee. T. J. McLoughlin, U. S. Steel Corp., presented a paper, *The Attainment of Maximum Open Hearth Production.* L. A. Lambing, Jones & Laughlin Steel Co., served as Technical Chairman. Officers of the Section are: J. F. Pollack, Chairman; H. G. Grim, Vice-Chairman; C. E. Williams, Secretary; and C. Longenecker, Treasurer. Future plans of the Sections call for a golf party and an Off-the-Record meeting.

J. F. POLLACK
Jones and Laughlin Steel Corp., Pittsburgh
Chairman, Pittsburgh Section



J. R. BRADY
Wisconsin Steel Co., Chicago
Chairman, Chicago Section

CHICAGO SECTION

The first meeting of the Chicago Section was an all day session held at the Del Prado Hotel, March 12, and was devoted to operating and technical discussion. More than 250 persons attended the technical sessions, while 200 persons, including many suppliers, were seated at the Fellowship Dinner.

Furnace and Construction and Design was the theme of a second meeting held at Phil Smidts, April 21. A two-hour discussion followed dinner, with M. F. Yarotsky in the role of Technical Chairman. The meeting covered current practices and new ideas being promoted to reduce furnace outage time and to increase production.

The steel strike forced postponement of a golf outing scheduled for June 3, to September 16. A record attendance saw 125 on the fairways and 300 at the dinner. The committee, which arranged details of the day and the multitude of prizes, was composed of: R. Dwyer, Chairman; M. E. Nickel, T. Hess, G. W. Johnson, P. Haserodt, D. Cameron, and R. Porter.

Activities for the year were completed with a meeting at Phil Smidts, October 6 with 125 Section members attending. C. Cravens was Chairman of the meeting. The subject of the meeting was *Methods and Procedures Used in Shutting Down and Lighting Up Open Hearth Furnaces for Various Reasons.* First meeting of 1953 was held March 11 at the Del Prado Hotel.

Officers for the years 1953 to 1954, and 1954 to 1955 are: R. J. McCurdy, Chairman; T. Hess, Vice Chairman; and E. Speer, Secretary-Treasurer.

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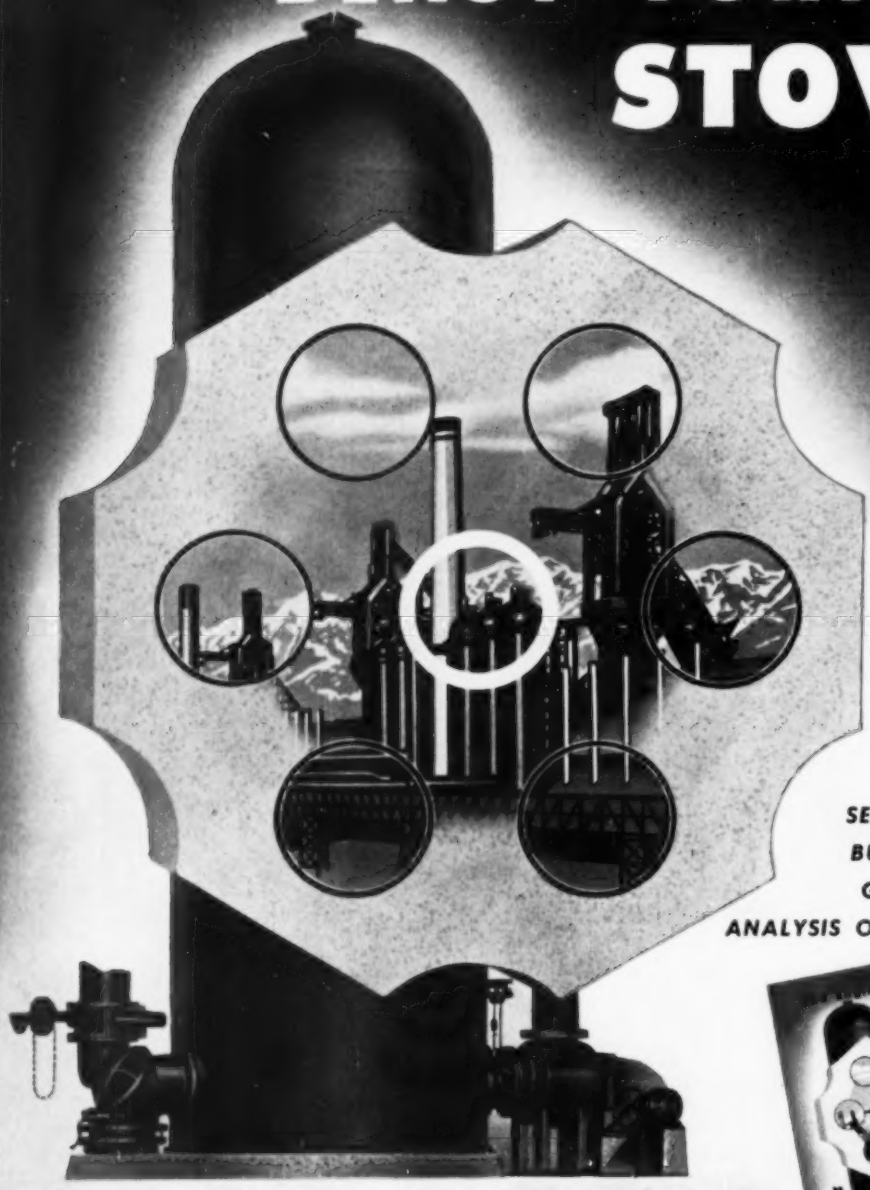

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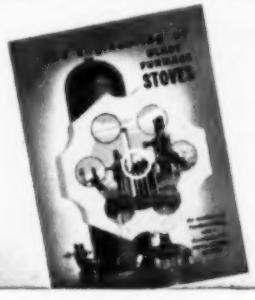

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NORTHERN OHIO SECTION

The Northern Ohio Section Annual Spring Meeting was held Mar. 4, 1952 at the Pick-Ohio Hotel, Youngstown. Included on the technical program were: *Factors Influencing Heat Time; Silica Brick Quality; Labor Saving Devices;* and *Spectrographic Control of the Blow and Manganese Conservation.* Ten minute papers were presented by district producers on each subject followed by a discussion period moderated by Co-Chairmen T. B. Carpenter and E. Holstein.

Attendance at the golf party, held at Tippecanoe Country Club August 21, was cut somewhat by threatening weather, coupled with strike-delayed vacations. C. F. Swank received a suckling pig which he will return next year fattened for roasting.

The Executive Committee elected T. B. Carpenter Chairman for 1952 to 1953. The election was necessitated by the transfer of E. E. McGinley, Section Chairman, to division superintendent of the Homestead Works. The golf party date has been changed from August to June 18. Bruce Ramage has been elected Secretary-Treasurer of the Section. The Annual Technical session was held Feb. 24, 1953, at the Pick-Ohio Hotel. John J. Golden, assistant to the vice-president, steel production, U. S. Steel Corp., and Chairman of the National Open Hearth Steel Committee was the main speaker at the dinner.

The Northern Ohio section is initiating a Best Paper Award Contest. A prize of $100 and a certificate will be awarded for the best paper submitted by Nov. 1, 1953. In a case where the paper is jointly authored by two or more persons the prize will be divided, but no certificate issued. If judges feel no paper submitted merits an award, none will be given.

GEORGE B. McMEANS
Kaiser Steel Corp., Fontana, Calif.
Permanent Chairman, Western Section

J. M. FAHEY
American Brake Shoe Co.
Presiding Chairman, Western Section

WESTERN SECTION

Western Section meetings, all of which were held at the Roger Young Auditorium in Los Angeles during the year 1952-53 started off September 17 with an address by Paul C. Withers, consultant, Merchant & Manufacturers Assn., Los Angeles. He spoke to Section members on *Employee-Management Relations.* A. H. Zeilinger, Colorado Fuel & Iron Co., Pueblo, Col., discussed *Safety for Tomorrow* with members Nov. 12, 1952.

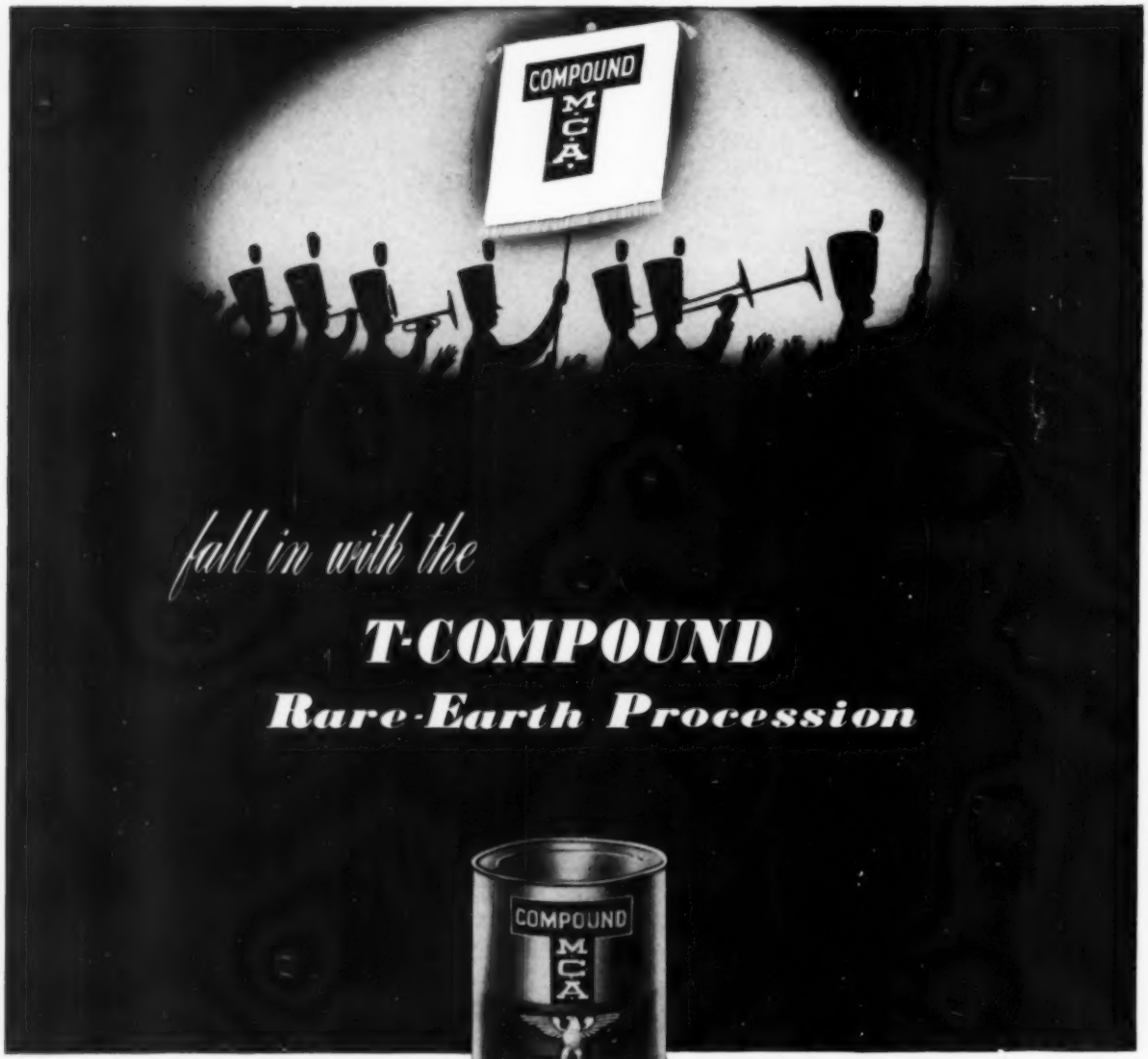
Jan. 21, 1953 marked a panel discussion on *Electric Steel Melting Practices for Casting Production.* Six representatives from local foundries made up the panel. They were:

William Mitchult, Utility Steel Casting Co.; Glen Middleton, National Supply Co.; Osman Erickson, Hanford Foundry Co.; J. M. Fahey, American Manganese Steel Div., American Brake Shoe Co.; Carl Wissman, Los Angeles Steel Casting Co.; and William Adams, Alloy Steel & Metals Co.

At the most recent meeting, March 18, R. K. Kulp, Electro Metallurgical Co., Div. Union Carbide & Carbon Co., addressed Section members on *Additional Agents for Steelmaking.*

Officers who will serve for the current year are: George B. McMeans, Permanent Chairman; J. M. Fahey, Presiding Chairman; Ralph J. Price, Vice-Chairman; and R. C. Elms, Secretary-Treasurer.

Attendance at meetings was reported good, with gatherings averaging between 60 and 70 members at all sessions.



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A special product, **RARE-MET T-COMPOUND**, developed by Molybdenum Corporation, is thoroughly approved and readily available for use in steels needing help in hot workability and specific physical properties.

Having the world's largest rare-earth deposits, the Molybdenum Corporation has devoted special research to these materials and can give advice on a wide variety of applications.

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SOUTHWESTERN SECTION

The first meeting of the Southwestern Section was held February 1952 at the Lennox Hotel, St. Louis, Mo. The 1952 Fall Meeting, held October 9 and 10 was featured by the hospitality of Keystone Steel & Wire, hosts to the 175 steel men who registered.

Highlight of the trip through the steel mills was a close-up inspection of a basic end furnace which had been repaired and was to be placed back in operation the day following the meeting. It was the first time many of those who attended were able to inspect an open hearth furnace at all three levels from the flues to the hearth.

Seven major topics were discussed at the meeting, including various phases of steelmaking, but of unusual interest was the information that electric furnaces were definitely on a competitive plane from the economic standpoint, with the open hearth. Another topic which gained much attention was the *Use of High Pressure Natural Gas as an Atomizing Agent for Fuel Oil*. It was indicated that the emissivity value of the flame produced by this firing method will make it possible to produce steel in the open hearth with less than 3 million btu per ton of ingots.

Past chairmen of the National Open Hearth Committee attending the meeting were E. L. Ramsey and A. H. Sommer. William Carpenter, Colorado Fuel & Iron Corp. and Hugh Clark of the American Steel Foundries Co. were Meeting Chairmen.

The first meeting of 1953 at the Lennox Hotel saw 146 registrants. Topics presented were: *Effects of Uptake Area on Furnace Performance*, by Carl Henzelman; *Use of Rammed and Castable Refractories in Runner, Bottoms, Etc.*, by Russ Fayles; *Effects of Reduced Aluminum Deoxidation on Cast Steel*, by Al Fastabend; *Use of Hydraulically Operated Ladle Equipment*, by Charles Cravens; and *Metallurgical Aspects of Hot Tearing*, by Charles W. Briggs.

Bud Blattner, St. Louis Browns radio announcer, talked about the baseball team after the dinner. The Southwestern Section has expanded to include the Atlantic Steel Co., Atlanta, Ga., and the Lone Star Steel Co., Lone Star, Texas.

Feature of the Fall Meeting at Longview, Texas will be the Harlem Globetrotters, basketball sensations. After the plant visit, October 15, the Section registrants will travel to Dallas for a day meeting at the Baker Hotel, October 16. There will be a football game at the Cotton Bowl October 17, the following day.

Harry Hampe has been appointed the new Social Secretary of the Section. Henry Day will be his assistant.

HAROLD P. GAW
Armco Steel Corp., Middletown, Ohio
Chairman, Southern Ohio Section

SOUTHERN OHIO SECTION

The Southern Ohio Section held its 16th annual Off-the-Record meeting at the Deshler-Wallick Hotel in Columbus, Oct. 3 and 4, 1952, with 228 members and guests attending. Vernon W. Jones, Section Chairman, presided. The morning session dealt with operating and combustion problems and was under the leadership of W. O. Richmond. The sessions covered human relations in the furnace shop, plastic and castable refractories, shutdown and holding practices, status of insulating and sealing, and progress in combustion.

Practice and quality subjects were covered during the afternoon session, with G. K. Manning and A. H. Osborne serving as Co-Chairmen. Discussion included autopour, jet tapping problems, slag thimble practices, boron and rare earth metals in the scrap charge, and substitutes for aluminum.

Fred Smith, vice-president, industrial relations, William Powell Co., was the main speaker at the dinner which concluded the meeting. John J. Golden, assistant to the vice-president, U. S. Steel Corp., was toastmaster. One hundred and forty-five persons attended the affair.

The Elks Country Club at Portsmouth, Ohio was the scene of the section's first golf party, June 7, 1952. Twenty-six members and guests turned out for the affair. All were in agreement that the event should become an annual affair and preliminary plans were made for 1953. Time and place will be announced.

Officers appointed to serve through the 1954 meeting are: Chairman, Harold P. Gaw; Secretary-Treasurer, Richard W. Lewry.

The Deshler-Wallick in Columbus will again house the annual meeting, scheduled for Oct. 30 and 31, 1953.

SAMUEL NAISMITH
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U. S. Steel Corp.

E. K. MILLER
PAST-CHAIRMAN
Jones & Laughlin Steel Corp.

Blast Furnace, Coke Oven And Raw Materials Committee

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AIME

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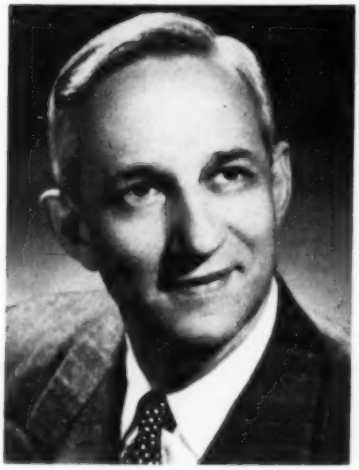
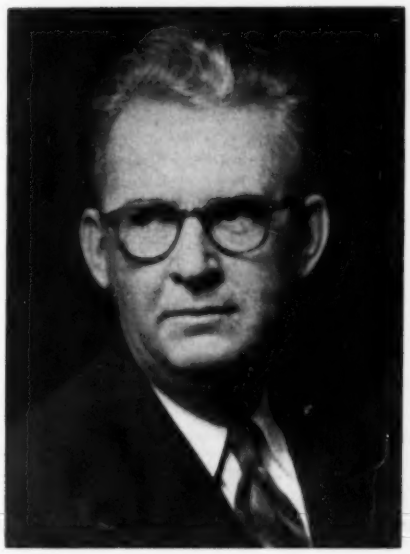
Keystone Steel & Wire Co.



L. R. BERNER
VICE-CHAIRMAN
Inland Steel Co.

ERNEST KIRKENDALL
SECRETARY, TREASURER
AIME

J. J. GOLDEN
CHAIRMAN
U. S. Steel Co.



National Open Hearth Steel Committee

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University of Minnesota

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Alan Wood Steel Co.

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Kaiser Steel Corp.

A. W. Thornton
National Tube Div., U. S. Steel Corp.

H. J. Walker
Republic Steel Corp.

Blast Furnace, Coke Oven and Raw Materials Program

LUNCHEON
Tuesday, April 21
12:30 pm—Parlors D & E

Annual Luncheon and Business Meeting, Blast Furnace, Coke Oven and Raw Materials Committee

Samuel Naismith, Chairman

Everyone attending the Blast Furnace, Coke Oven and Raw Materials sessions is invited to attend this luncheon and annual business meeting.

MONDAY, APRIL 20

9:30 am to 12:15 pm—Chinese Room

AGGLOMERATION AND BENEFICIATION SESSION

Chairmen:

F. M. Hamilton, Agglomeration Supervisor, Ore Research Laboratory, Jones & Laughlin Steel Corp., Negaunee, Mich.

J. D. Saussaman, Blast Furnace Superintendent, Kaiser Steel Corp., Fontana, Calif.

1. **Beneficiation of Texas Ores:**
   W. R. Bond, Vice-President in Charge of Operations, Lone Star Steel Co., Lone Star, Texas.
2. **Quality Control of Blast Furnace Flue Dust Sinter:**
   E. C. Rudolphy, Petrographer and D. J. Carney, Chief Development Metallurgist, South works, U. S. Steel Corp., Chicago.
3. **Reduction-Oxidation Process for the Treatment of Taconites:**
   F. M. Stephens, Jr., Assistant Supervisor; Benny Langston, Research Engineer; and A. C. Richardson, Supervisor, Minerals Processing Div., Battelle Memorial Institute, Columbus.
4. **Sintering Fans—Construction and Application:**
   H. R. Phelps, Director, Contract Engineering, American Blower Corp., Detroit.

2:00 to 5:00 pm—Chinese Room

BLAST FURNACE GENERAL SESSION

Chairmen:

W. A. Cureton, Superintendent Blast Furnaces, National Tube Div., U. S. Steel Corp., McKeesport, Pa.

J. W. Cox, Superintendent Blast Furnaces, American Steel & Wire Div., U. S. Steel Corp., Donora, Pa.

1. **Further Studies of the Tuyere Zone of the Blast Furnace:**
   J. B. Wagstaff, Research Physicist, U. S. Steel Corp., Kearny, N. J.
2. **Experimental Smelting of Char-Ore Agglomerates in a Low Shaft Blast Furnace:**
   Herbert Kay, Process Engineer, Pittsburgh Consolidation Coal Co., Library, Pa.
3. **Use of Brazilian Ore in the Blast Furnace:**
   J. R. Lowe, Superintendent Blast Furnaces, Jones & Laughlin Steel Corp., Pittsburgh.
4. **Physically Hot Iron for the Open Hearth:**
   D. M. Morrison, Metallurgical Engineer, A. J. Boynton & Co., Chicago.

TUESDAY, APRIL 21

9:30 am to 12:15 pm—Empire State Room

COAL AND COKE SESSION

Chairmen:

H. W. Jackman, Chemical Engineer, Illinois State Geological Survey, Urbana, Ill.

Elliott Preston, General Superintendent, Koppers Co., Pittsburgh.

1. **Some Aspects of Latin American Coal Reserves:**
   J. D. Price, Superintendent Byproduct Coke Plant, Colorado Fuel & Iron Corp., Pueblo, Colo.
2. **Present and Future Aspects of Carbonization Research:**
   H. W. Nelson, Supervisor, Fuels Research and J. J. Ward, Consulting Chemist, Battelle Memorial Institute, Columbus.
3. **Gas Pressure Measurements Within the Coal Charge in Coke Ovens:**
   C. C. Russell, Manager, Coal Carbonization, Koppers Co., Pittsburgh.

9:30 am to 12:15 pm—Chinese Room

BLAST FURNACE BLOWING IN PRACTICE

Chairmen:

C. M. Squarcy, Assistant Superintendent Blast Furnaces, Inland Steel Co., E. Chicago, Ind.

R. P. Wheatly, Superintendent, Blast Furnaces Dept., Wisconsin Steel Works, Chicago.

1. **Preheating and Blowing in Practice at Inland:**
   R. J. Wilson, Blast Furnace Engineer, Inland Steel Co., E. Chicago.
2. **Method of Blowing in Blast Furnace from Bank:**
   W. W. Durfee, Superintendent Blast Furnaces, Lorain works, National Tube Div., U. S. Steel Corp., Lorain, Ohio.
3. **Drying and Blowing in Blast Furnaces:**
   H. M. Kraner, Ceramic Engineer, Bethlehem Steel Co., Bethlehem.

2:00 to 5:00 pm—Chinese Room

BLAST FURNACE OPERATION SESSION

Chairmen:

R. P. Liggett, Chairman, Blast Furnace Committee, Republic Steel Corp., Cleveland.

A. J. MacDonald, Assistant General Manager, Hanna Furnace Co., Buffalo.

1. **Blast Furnace Operation at High Top Pressure:**
   R. P. Towndrow and W. Banks, Colvilles Ltd., Tollcross, Glasgow, Scotland.
2. **Distribution of Burden Materials in a Blast Furnace Model:**
   R. L. Stephenson, Research Associate and F. C. Langenberg, Metallurgist, U. S. Steel Corp., Pittsburgh.
3. **Optimum Composition of Blast Furnace Slag as Deduced from Liquidus Data for the Quaternary System Lime-Magnesia-Alumina-Silica:**
   E. F. Osborn, R. C. DeVries, and K. H. Gee, Pennsylvania State College, State College, Pa., and H. M. Kraner, Ceramic Engineer, Bethlehem Steel Co., Bethlehem.
4. **Instrumentation for Blast Furnace Research:**
   D. I. Sinizer, J. De Piccolellis, and E. R. Poor, Arthur D. Little, Inc., Cambridge.

National Open Hearth Steel Program

MONDAY, APRIL 20

9:30 to 10:15 am—Ballroom

OPEN HEARTH GENERAL SESSION

1. **Welcoming Remarks**

   By J. J. Golden, Assistant to Vice-President, U. S. Steel Corp., Pittsburgh. General Chairman, National Open Hearth Steel Committee, AIME.

2. **Announcements and Reports**

3. **McKune Award Paper**

10:30 am to 12:15 pm—Ballroom

TRAINING PERSONNEL

Chairmen:

M. F. Yarotsky, Superintendent Steel Production, U. S. Steel Corp., Chicago.
C. W. Conn, Manager Open Hearth and Electric, Ford Motor Co., Dearborn.

1. **Training Open Hearth Personnel—Supervision—Furnace Crews—Casting Crews—Maintenance Crews:**

   A. New Shops
   William Whigham, Jr., Assistant Vice-President, Industrial Relations Administration, U. S. Steel Corp., Pittsburgh.
   H. L. Tear, Assistant Open Hearth Superintendent, Jones & Laughlin Steel Corp., Pittsburgh.
   R. P. Carpenter, Open Hearth Superintendent, Republic Steel Co., Cleveland.
   H. A. Parker, Division Superintendent Open Hearth, Fairless works, U. S. Steel Corp., Morrisville, Pa.
   Discussion by L. R. Berner, Superintendent Steel Production, Inland Steel Co., E. Chicago; J. B. Brashear, Superintendent Open Hearth, Lone Star Steel Co., Lone Star, Texas.
   B. Old Shops
   E. L. Wentz, Division Superintendent Steel Production, Ohio works, U. S. Steel Corp., Youngstown.
   M. K. Morris, Assistant Superintendent No. 2 and 4 Open Hearth, Bethlehem Steel Co., Bethlehem.
   C. H. Alexander, Assistant Open Hearth Superintendent, Lukens Steel Co., Coatesville.

10:30 am to 12:15 pm—Empire State Room

ACID OPERATING

Chairmen:

C. F. Christopher, Metallurgist, Continental Foundry & Machine Co., E. Chicago.
D. L. McBride, Supervisor Research Associates, U. S. Steel Corp., Pittsburgh.

1. **Acid Open Hearth Sand:**

   D. C. Williams, Associate Professor, Dept. of Industrial Engineering, Ohio State University, Columbus.

2. **Sand for Acid Open Hearth Furnaces:**

   G. R. Fitterer, Dean of Engineering, University of Pittsburgh, Pittsburgh.

   Discussion by C. R. Funk, Chief Metallurgist, American Locomotive Co., Latrobe, Pa.; G. Baldwin, Standard Steel Works Div., Baldwin-Lima-Hamilton Corp., Burnham, Pa.; T. E. Dann, Open Hearth Superintendent, Continental Foundry & Machine Co., E. Chicago.

3. **Question and Answer Discussions:**

   A. What is the current role of carbon substitutes? What substitutes are being used?

   B. What are your manganese efficiencies? What is being done to increase them?

   C. What steps are being taken in the manufacture of large forging ingots to offset the harmful effects of the increasingly higher sulphurs?

2:00 to 5:00 pm—Empire State Room, D & E

OPERATING METALLURGY

Chairmen:

H. B. Emerick, Assistant to Vice-President, Technology, Jones & Laughlin Steel Corp., Pittsburgh.
J. L. Walton, Open Hearth Superintendent, Bethlehem Steel Co., Lackawanna, N. Y.

1. **Quality Problems—Open Hearth vs Electric Furnace for Similar Grades of Carbon and Alloy Steels:**

   A. Chemical composition control
   B. Deoxidation practice
   C. Pit practice
   A. H. Osborne, Senior Metallurgist, Armco Steel Corp., Middletown, Ohio.
   B. R. Queneau, Chief Metallurgist, U. S. Steel Corp., Duquesne, Pa.
   Walter Huhn, Metallurgist, Crucible Steel Co. of America, Midland.

2. **Production and Quality of AISI C-1200 Series Screw Steels:**

   A. Furnace practice

ANNUAL FELLOWSHIP DINNER

Tuesday, April 21

6:30 pm—Niagara Room

Reception and Cocktail Party for dinner guests

7:00 pm—Ballroom

Annual Fellowship Dinner

Toastmaster: D. R. Loughrey, Superintendent Open Hearth, Pittsburgh works, Jones & Laughlin Steel Corp., Pittsburgh

Speaker: William H. Durrell, General Manager, Iron Ore Co., Montreal, Canada.

Music: Choral selections by courtesy of the Stelco Male Chorus, Steel Co. of Canada, Ltd., directed by Roderick A. Shepherd.

B. Surface quality
C. Machinability

S. Feigenbaum, Chief Metallurgist, Pittsburgh Works, Jones & Laughlin Steel Corp., Pittsburgh.

I. A. Sirel, Steel Plant Metallurgist, Youngstown Sheet & Tube Co., E. Chicago.

3. **Rimmed vs Capped Steel:**

A. Applications
B. Yields
C. Quality of product

R. D. Hindson, Works Metallurgist, Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

W. H. Carpenter, Process Control Metallurgist, Colorado Fuel & Iron Corp., Pueblo, Colo.

A. N. Swanson, Chief Process Metallurgist, Chicago District, U. S. Steel Corp., Chicago.

4. **Factors Affecting Surface Quality of Aluminum Killed Deep Drawing Sheet Steels:**

A. Furnace practice
B. Deoxidation practice and aluminum control
C. Processing factors

R. J. Walter, Supervisor, Quality Control, Wheeling Steel Corp., Steubenville, Ohio.

A. V. Lang, Observer Foreman, Brier Hill Works, Youngstown Sheet & Tube Co., Youngstown.

E. L. Robinson, Chief Process Metallurgist, Pittsburgh District, U. S. Steel Corp., Pittsburgh.

5. **Thermocouple Bath Temp Measurement:**

A. Instrument design and maintenance
B. Degree of temperature control exercised
C. Effect on steel quality

J. H. Richards, Research Associate, U. S. Steel Corp., Pittsburgh.

T. B. Winkler, Metallurgist, Bethlehem Steel Co., Lackawanna, N. Y.

John Orton, Metallurgist, Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

6. **Present Day Methods for Coating Molds:**

General discussion if time permits.

2:00 to 5:00 pm—Ballroom

REFRACTORIES AND MASONRY

Chairmen:

R. R. Fayles, Superintendent, Refractories and Fuel, Lukens Steel Co., Coatesville, Pa.

L. L. Wells, Jr., Mason Superintendent, South Works, U. S. Steel Corp., Chicago.

1. **Effect of Restricted Uptake Design on Refractory Consumption and Production Rate:**

E. Speers, Division Superintendent Steel Production, Gary works, U. S. Steel Corp., Gary, Ind.

M. J. Smith, Open Hearth Superintendent, Ford Motor Co., Dearborn, Mich.

2. **Economics of Port End Construction:**

A. Large plants

E. Speers, Division Superintendent Steel Production, Gary works, U. S. Steel Corp., Gary, Ind.

A. J. Voss, Masonry Superintendent, Inland Steel Co., E. Chicago.

B. Small plants

A. H. Sommer, Vice-President, Keystone Steel & Wire Co., Peoria, Ill.

W. J. Scharfenaker, Mason Superintendent, Ford Motor Co., Dearborn.

3. **Recent Developments for Flue and Slag Removal:**

A. Results obtained with hinged slag pocket door

M. H. Weir, Assistant General Superintendent, Masonry Dept., Sheffield Steel Corp., Houston.

B. Use of special explosives for slag removal

J. O. Dague, Assistant Superintendent, Mechanical Dept., Bethlehem Steel Co., Lackawanna.

W. E. Brandt, Superintendent No. 5 Open Hearth, Homestead works, U. S. Steel Corp., Munhall, Pa.

C. Flue dust removal

John Peterson, Turn Foreman Open Hearth, Crucible Steel Co. of America, Midland.

4. **Monolithic Refractories in Furnace Spouts:**

V. W. Jones, Superintendent Steel Production, Armco Steel Corp., Middletown, Ohio.

G. M. Burrier, Assistant General Superintendent, Crucible Steel Co. of America, Midland, Pa.

J. C. MacNeill, Superintendent Open Hearth No. 2 & 4, Bethlehem Steel Co., Bethlehem.

5. **Checker Problems — Quality, Thickness, Life, Preheat:**

A. Conventional settings
B. Multiple pass settings
C. Auxiliary stack checkers

E. Richards, Superintendent Open Hearth & Foundry, U. S. Steel Corp., Geneva, Utah.

G. C. Lawton, Superintendent No. 2 Open Hearth, Inland Steel Co., E. Chicago, Ind.

C. N. Straney, Open Hearth Superintendent, Weirton Steel Co., Weirton, W. Va.

6:00 pm—Parlors A & B—Mezzanine

NATIONAL OPEN HEARTH COMMITTEE

Dinner and business meeting of Open Hearth Executive Board

TUESDAY, APRIL 21

9:30 am to 12:15 pm—Ballroom

FUELS AND COMBUSTION

Chairmen:

P. F. Kinyoun, Fuel Engineer, Lackawanna Plant, Bethlehem Steel Co., Bethlehem, Pa.

D. R. Mathews, Open Hearth Superintendent, Alan Wood Steel Co., Conshohocken, Pa.

1. **Continuous O_2 Analysis for Open Hearth Combustion Control:**

F. P. Hubbell, Superintendent Fuel Dept., U. S. Steel Corp., Munhall, Pa.

Discussion by E. T. W. Bailey, Combustion Engineer, Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

2. **Atomization of Liquid Fuels as Related to the Overall Operation of Open Hearth Furnaces (Tonnage and Refractories):**

G. C. Primm, Superintendent of Fuel Utilization, U. S. Steel Corp., Chicago.

Discussion by G. H. Krapf, Assistant Chairman Fuel and Power Committee, U. S. Steel Corp., Pittsburgh.

3. **Significance, Factors Affecting, and Maintenance of Air Preheat:**

J. H. Kelley, Assistant Superintendent Open Hearth and Bessemer and G. E. Wenzel, Open Hearth Foreman, Bethlehem Steel Co., Sparrows Point, Md.

Discussion by J. S. Marsh, Assistant Manager Research, Bethlehem Steel Co., Bethlehem.

4. **Discussion of Firing Methods:**

A. Up to the operating personnel entirely

J. H. Mateer, Open Hearth Superintendent, Lukens Steel Co., Coatesville.

Discussion by E. L. Wentz, Division Superintendent Steel Production, U. S. Steel Corp., Youngstown.

B. Scheduling maximums

J. T. Clisham, Jr., Superintendent No. 1 Open Hearth, Bethlehem Steel Co., Sparrows Point, Md.

C. By roof temperature measurements

a. Manual

L. N. McDonald, Superintendent of Utilities, U. S. Steel Corp., Braddock, Pa.

b. Automatic

F. S. Swaney, Combustion Engineer, Steam Efficiency & Combustion Dept., Jones & Laughlin Steel Corp., Pittsburgh.

Discussion by A. W. Thornton, Assistant General Superintendent, National Tube Div., U. S. Steel Corp., McKeesport, Pa.

Discussion by E. Richards, Division Superintendent, Open Hearth & Foundry, U. S. Steel Corp., Geneva, Utah.

5. **Heating Up Open Hearth Furnaces After Rebuilds:**

C. N. Jewart, Ceramic Engineer, Bethlehem Steel Co., Lackawanna, N. Y.

2:00 to 5:00 pm—Ballroom

HOT METAL BASIC OPERATIONS

Chairmen:

H. H. Northrup, Open Hearth Superintendent, Republic Steel Corp., Buffalo.

G. H. Todd, Assistant General Superintendent, Armco Steel Corp., Ashland, Ky.

1. **Recent Trends in Furnace Design — New Plants:**

H. A. Parker, Division Superintendent, Steel Production, U. S. Steel Corp., Morrisville, Pa.

A. K. Moore, Open Hearth Superintendent, Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

Discussion

Jones & Laughlin Steel Corp.

Keystone Steel & Wire Co.

H. R. Ryan, Superintendent No. 2 Open Hearth, Youngstown Sheet & Tube Co., Indiana Harbor, Ind.

Geneva Works, U. S. Steel Co.

2. **New Bottoms and Refractories Used in Bottom Repair:**

Jones & Laughlin Steel Corp.

J. F. Pollack, General Foreman No. 4 Open Hearth, Pittsburgh works, Jones & Laughlin Steel Corp., Pittsburgh.

A. M. Kroner, Assistant Superintendent No. 3 Open Hearth, Inland Steel Co., E. Chicago.

Discussion by H. R. Ryan, Superintendent No. 2 Open Hearth, Youngstown Sheet & Tube Co., Indiana Harbor, Ind.

3. **Significance Study of Open Hearth Variables:**

W. R. Weaver, Director Steel Conservation and Quality Control, Republic Steel Corp., Cleveland.

Discussion by W. A. Olsen, Chief Process Metallurgist, South works, U. S. Steel Corp., Chicago and J. R. Brady, Supervisor Research, Wisconsin Steel Works, Chicago.

4. **Productivity by Use of Oxygen Lance as Complicated by Sulphur Limitations:**

J. E. Hood, Assistant Superintendent Open Hearth, Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

L. R. Berner, Superintendent Steel Production, Inland Steel Co., E. Chicago, Ind.

5. **Mechanical Aids in the Open Hearth:**

A. Jet Tappers

R. W. Smith, Superintendent No. 4 Open Hearth, U. S. Steel Corp., Gary, Ind.

B. Hydraulically Operated Ladle Stoppers

T. J. Hoby, General Foreman No. 2 Melt Shop, Republic Steel Corp., Chicago, Ill.

C. Upkeep of Doors and Frames

2:00 to 5:00 pm—Empire State Room

COLD METAL AND BASIC FOUNDRY PRACTICE

Chairmen:

Loren B. Wright, Open Hearth Superintendent, Symington-Gould Corp., Depew, N. Y.

J. E. Wilbanks, Open Hearth Superintendent, Atlantic Steel Co., Atlanta, Ga.

1. **Economics of Electric Furnace vs Open Hearth:**

T. R. Scott, Open Hearth Superintendent, Sheffield Steel Co., Houston.

J. E. Wilbanks, Open Hearth Superintendent, Atlantic Steel Co., Atlanta.

Clarence King, Open Hearth Superintendent, Sheffield Steel Co., Kansas City, Mo.

2. **Effect of Reduced Aluminum Deoxidation on Cast Steel:**

A. W. Fastabend, Chief Chemist, American Steel Foundries, E. St. Louis, Ill.

3. **Effects of Ladle Sizes, Refractories, etc., on Steel Quality:**

C. F. Henzelman, Superintendent No. 2 Open Hearth Dept., Granite City Steel Co., Granite City, Ill.

4. **Rammed and Castable Refractories for Open Hearth Service:**

R. R. Fayles, Superintendent Refractories & Fuel, Lukens Steel Co., Coatesville.

5. **Recarb Heats with Coal or Coke Injected by Compressed Air:**

R. C. Buehl, Chief Ferrous Pyrometallurgy Branch, Bureau of Mines, Pittsburgh.

Annual Steel Capacity (Ingots and Steel for Castings) As of Jan. 1, 1953

	Open Hearth		Bessemer		Electric and Crucible		Total Annual Capacity Net Tons
	No.	Annual Capacity Net Tons	No.	Annual Capacity Net Tons	No.	Annual Capacity Net Tons	
Alan Wood Steel Co.	8	625,000					625,000
Allegheny Ludlum Steel Corp.	6	240,000			35	649,000	889,200
American Locomotive Co.	6	181,000					181,000
Armco Steel Corp.	25	2,588,000			9	369,000	2,984,000
*Sheffield Steel Corp.	14	1,434,000			2	300,000	1,734,000
Atlantic Steel Co.	3	188,000			1	112,000	300,000
Babcock & Wilcox Co.					4	229,450	229,450
Baldwin-Lima-Hamilton Corp.	5	169,920			1[a]	40	169,960
Barium Steel Corp.							
*Central Iron & Steel Co.	5	360,000			1	46,000	406,000
*Industrial Forge & Steel, Inc.	2	48,600					48,600
*Phoenix Iron & Steel Co.	6	432,000					432,000
Bethlehem Steel Corp.							
*Bethlehem Steel Co.	127	16,206,000	3	336,000	4	158,888	16,700,000
*Bethlehem Pacific Coast Steel Corp.	10	498,000			3	402,000	900,000
Borg-Warner Corp.					4	64,000	64,000
Bolardi Steel Corp.					2	53,700	53,700
Braeburn Alloy Steel Corp.					2	20,730	20,730
Byers Co., A. M.					2	75,000	75,000
Cameron Iron Works, Inc.					2	58,800	58,800
Carpenter Steel Co.					7	85,800	85,800
Colorado Fuel & Iron Corp.	27	2,231,570					2,231,570
*Roebling's Sons Corp., J. A.	9	235,000					235,000
Columbia Tool Steel Co.					2	6,600	6,600
Connors Steel Co.					3	67,500	67,500
Continental Steel Corp.	5	394,000					394,000
Copperweld Steel Co.					7	618,380	618,380
Crucible Steel Co. of America	10	972,000			17	378,700	1,350,700
Damascus Tube Co.					3	1,800	1,800
Detroit Steel Corp.	10	660,000					660,000
Disston & Sons, Inc., H.					2	25,000	25,000
Eastern Stainless Corp.					3	32,000	32,000
Edgewater Steel Co.	3	89,890					89,890
Empire Steel Corp.	7	455,000					455,000
Erie Forge & Steel Corp.	5	234,000					234,000
Fitzl & Sons Co., A.					2	33,000	33,000
Firth Sterling Inc.					3	20,040	20,040
Ford Motor Co.	10	1,370,200			17	278,000	1,648,200
General Services Administration	2	60,000			1	12,300	72,300
Granite City Steel Co.	13	720,000					720,000
Green River Steel Corp.					2	198,000	198,000
Harrisburg Steel Corp.	3	100,750					100,750
Heppenstall Co.	2	50,470			1	5,080	55,550
Hooter Steel Corp.					1	16,920	16,920
Inland Steel Corp.	40	4,500,000					4,500,000
International Harvester Co.	11	1,000,000					1,000,000
Isaacson Iron Works					2	102,000	102,000
Jessop Steel Co.					4	33,490	33,490
Jones & Laughlin Steel Corp.	38	5,823,000	3	582,000	1	1,500	6,406,500
Joslyn Mfg. & Supply Co.					3	37,500	37,500
Judson Steel Corp.	3	76,500					76,500
Kaiser Steel Corp.	9	1,536,000					1,536,000
Keystone Steel & Wire Co.	4	400,000					400,000
Kilby Steel Co.					3	34,020	34,020
Knoxville Iron Co.					2	38,000	38,000
Laclede Steel Co.	4	410,000					410,000
Latrobe Steel Co.					5	24,000	24,000
LeTourneau, Inc., R. G.					3	138,600	138,600
Lukens Steel Co.	12	675,000					675,000
McLouth's Steel Corp.					4	579,700	579,700
Mesta Machine Co.	4	85,000			1	20,000	105,000
Midvale Co.	4	184,920			7	140,030	324,950
National Forge & Ordnance Co.					3	25,000	25,000
National Steel Corp.							
*Great Lakes Steel Corp.	17	3,150,000	2[b]				3,150,000
*Weirton Steel Co.	13	2,500,000	2[b]				2,500,000
National Supply Co.					3	50,200	50,200
Newport News Shipbuilding & Dry Dock Co.					3	12,000	12,000
Newport Steel Corp.	7	375,300			3	333,200	708,500
Northwest Steel Rolling Mills, Inc.					2	42,000	42,000
Northwestern Steel & Wire Co.					5	825,000	825,000
Ohio River Steel Div., L. Berkman Co.	4	136,080					136,080
Oregon Steel Mills					3	110,000	110,000
Pacific States Steel Corp.	3	198,000			4	100,000	298,000
Pittsburgh Steel Co.	12	1,320,000					1,320,000
Republic Steel Corp.	78	8,222,000	2	665,000	26	1,375,000	10,262,000
Rotary Electric Steel Co.					5	425,000	425,000
Seidelhuber Steel Rolling Mill Corp.					1	60,000	60,000
Sharon Steel Corp.	19	1,478,000			2	72,000	1,550,000
Simonds Saw & Steel Co.					3	21,600	21,600
Southwest Steel Rolling Mills					1	45,000	45,000
Stanley Works	3	188,280					188,280
Texas Steel Co.					2	22,320	22,320
Timken Roller Bearing Co.					9	625,200	625,200
Union Electric Steel Corp.					2	26,760	26,760
U. S. Steel Corp.							
*U. S. Steel Corp., Central Operations	224	23,380,000	8[c]	1,284,000	9	357,000	25,021,000
*American Steel & Wire Div.	26	2,093,000					2,093,000
*Columbia-Geneva Steel Div.	21	2,274,000			1	12,000	2,286,000
*National Tube Div.	15	2,434,000	6	1,110,000			3,544,000
*Tennessee Coal & Iron Div.	23	3,455,000	3[b]				3,455,000
Universal-Cyclops Steel Corp.					5	70,160	70,160
Vanadium-Alloys Steel Co.					3	11,910	11,910
*Colonial Steel Co.					2	29,820	29,820
Vulcan Crucible Steel Co.					2	9,600	9,600
Washburn Wire Co.	4	93,000					93,000
W. Va. Steel & Mfg. Co.					1	78,840	78,840
Wheeling Steel Corp.	11	1,440,000	2	420,000			1,860,000
Youngstown Sheet & Tube Co.	39	4,707,500	2	240,000			4,947,500
Grand Total	971	102,677,980	33[d]	4,637,000	278[e]	10,232,490	117,547,470

* Indicates subsidiary. [a] Crucible furnace. [b] Used in melting charge for open hearth furnaces. [c] Includes 3 converters used only in melting charge for open hearth furnaces. [d] Includes 10 converters used only in melting charge for open hearth furnaces. [e] Includes 1 crucible furnace, annual capacity, 40 tons.

Annual Capacity of Blast Furnaces as of Jan. 1, 1953

	Pig Iron		Ferroalloys		Total
	No. of Stacks	Annual Capacity Net Tons	No. of Stacks	Annual Capacity Net Tons	Annual Capacity Net Tons
Alan Wood Steel Co.	2	454,800			454,800
Armco Steel Corp.	5	1,341,000			1,341,000
*Sheffield Steel Corp.	1	300,000			300,000
Barium Steel Corp.					
*Chester Blast Furnace, Inc.	1	200,000			200,000
Bethlehem Steel Co.	30	11,284,000	2	216,000	11,500,000
Colorado Fuel & Iron Corp.	7	1,501,200			1,501,200
Crucible Steel Co. of America	3	895,000			895,000
Detroit Steel Corp.	1	264,700			264,700
Eastern Gas & Fuel Associates	1	191,100			191,100
Ford Motor Co.	3	1,039,120			1,039,120
Globe Iron Co.			1	100,000	100,000
Granite City Steel Co.	2	450,000			450,000
Inland Steel Co.	8	2,638,950			2,638,950
Interlake Iron Corp.	6	1,402,670			1,402,670
International Harvester Co.	3	731,000			731,000
Jackson Iron & Steel Co.			1	93,000	93,000
Jones & Laughlin Steel Corp.	13	4,412,000			4,412,000
Kaiser Steel Corp.	2	876,000			876,000
Lavino & Co., E. J.			2	112,000	112,000
Lone Star Steel Co.	1	385,000			385,000
National Steel Corp.					
*Great Lakes Steel Corp.	4	1,680,000			1,680,000
*Hanna Furnace Corp.	3	680,000	1	120,000	800,000
*Weirton Steel Co.	4	2,000,000			2,000,000
New Jersey Zinc Co.			2	112,000	112,000
Newport Steel Corp.	1	136,800			136,800
Pittsburgh Coke & Chemical Co.	3	836,500			836,500
Pittsburgh Steel Co.	3	954,000			954,000
Republic Steel Corp.	22	7,220,000			7,220,000
Sharon Steel Corp.	3	709,620			709,620
Shenango Furnace Co.	2	423,100			423,100
Sloss-Sheffield Steel & Iron Div., United States Pipe & Foundry Co.	4	491,710			491,710
Tennessee Products & Chemical Corp.	3	217,740			217,740
Tonawanda Iron Div.	1	171,000			171,000
U. S. Steel Corp.					
*U. S. Steel Corp., Central Operations	51	18,700,500	4	335,400	19,035,900
*American Steel & Wire Div.	6	1,429,400			1,429,400
*Columbia-Geneva Steel Div.	5	1,682,700			1,682,700
*National Tube Div.	9	3,122,800			3,122,800
*Tennessee Coal & Iron Div.	9	2,836,800	*	33,500	2,870,300
Wheeling Steel Corp.	6	1,678,500			1,678,500
Woodward Iron Co.	4	772,630			772,630
Youngstown Sheet & Tube Co.	13	4,148,000			4,148,000
Grand Total	245	78,258,340	13	1,121,900	79,380,240

* Furnace included under pig iron.

Annual Coke Capacity as of Jan. 1, 1953

Company	Beehive		Other		Total
	No. of Ovens	Annual Capacity Net Tons	No. of Ovens	Annual Capacity Net Tons	Annual Capacity Net Tons
Alan Wood Steel Co.			151	600,000	600,000
Armco Steel Corp.			110	558,000	558,000
*Sheffield Steel Corp.			47	270,000	270,000
Bethlehem Steel Co.			2,057	10,450,000	10,450,000
Colorado Fuel & Iron Corp.			266	1,220,000	1,220,000
Crucible Steel Co. of America			213	831,600	831,600
Detroit Steel Corp.			108	550,000	550,000
Eastern Gas & Fuel Associates			204	1,112,000	1,112,000
Ford Motor Co.			183	1,434,450	1,434,450
Granite City Steel Co.			49	295,000	295,000
Inland Steel Co.			418	2,143,400	2,143,400
Interlake Iron Corp.			333	1,348,300	1,348,300
International Harvester Co.			148	664,300	664,300
Jones & Laughlin Steel Corp.	240	192,000	812	3,769,200	3,961,200
Kaiser Steel Corp.	297	100,000	135	566,000	666,000
Kaiser & Frazer Parts Corp.	500	300,000			300,000
Lone Star Steel Co.			78	438,000	438,000
National Steel Corp.					
*Great Lakes Steel Corp.			146	1,120,000	1,120,000
*Hanna Furnace Corp.			126	661,500	661,500
*Weirton Coal Co.	136	120,000			120,000
*Weirton Steel Co.			249	1,510,000	1,510,000
Pittsburgh Coke & Chemical Co.			140	1,000,000	1,000,000
Pittsburgh Steel Co.	574	426,000	74	500,000	926,000
Republic Steel Corp.	296	215,000	1,228	6,681,500†	6,896,500†
Sharon Steel Corp.			60	225,000	225,000
*Carpentertown Coal & Coke Co.	585	375,000			375,000
Sloss-Sheffield Steel & Iron Div., United States Pipe & Foundry Co.			150	800,000	800,000
Tennessee Products & Chemical Corp.			44	251,000	251,000
U. S. Steel Corp.					
*U. S. Steel Corp., Central Operations	2,912	2,073,750	3,169	15,244,820	17,318,570
*American Steel & Wire Div.			294	1,318,270	1,318,270
*Columbia-Geneva Steel Div.			308	1,212,300	1,212,300
*National Tube Div.			385	1,766,750	1,766,750
*Tennessee Coal & Iron Div.			572	2,945,550	2,945,550
Wheeling Steel Corp.			314	1,720,000	1,720,000
Woodward Iron Co.			256	938,000	938,000
Youngstown Sheet & Tube Co.			655	3,234,000	3,234,000
Grand Total	5,540	3,801,750	13,483	67,379,440	71,181,190

* Indicates subsidiary. † Includes 50 pct of coke capacity of Donner-Hanna Coke Corp., Buffalo, N. Y.

Acknowledgment is given to the American Iron & Steel Institute for permission to publish these official capacity figures. All data were compiled by AISI, and are correct as of Jan. 1, 1953.

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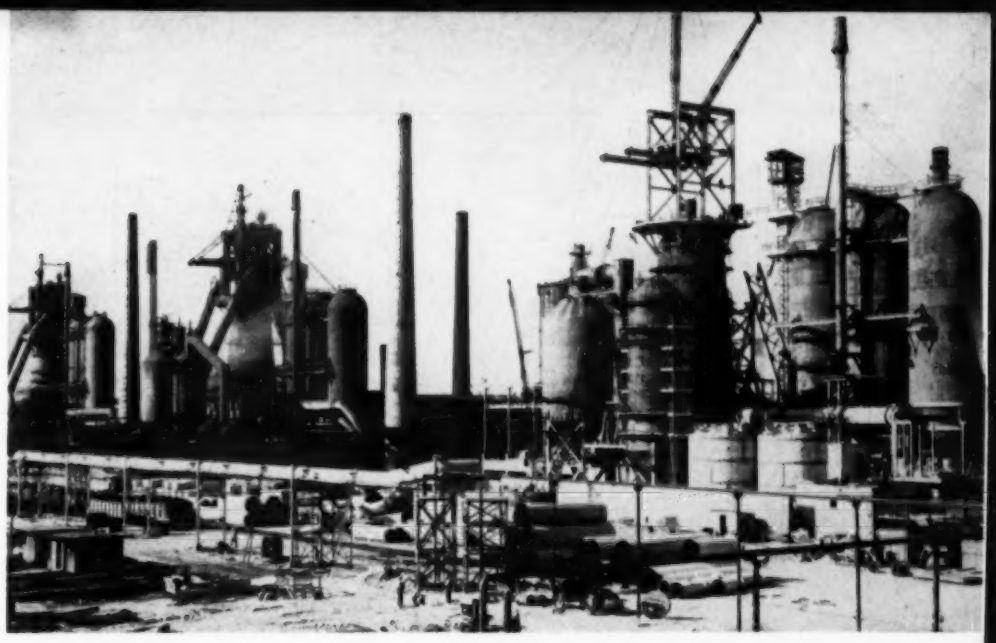

Fig. 1 — When blast furnace No. 3 is placed in operation at Fontana, Calif., by Kaiser Steel Corp., approximately 40 to 45 pct of the ore for the furnaces will be sintered. A second sintering machine is being installed for this purpose. This is a general view of the new blast furnace, looking northwest.

Kaiser Steel Production Record Set by Coke and Blast Furnace Practice

by W. C. Rueckel

BECAUSE of its phenomenally productive operating record, blast furnace practice at Fontana attracted great interest. The record was achieved despite utilization of coal believed to have poor coking qualities when compared with eastern coals. The unique practice which established this record thus helped to broaden the general concepts of usable coking coal reserves in the United States.

Fig. 2 shows the locations of coking coal and iron ore deposits drawn on by various steel plants of the U. S. Coal deposits supplying the steel industry in Utah, Colorado, and Illinois are of more recent geologic origin than are eastern and southern coals which have been used by the industry for years. It is well known that coals of recent geologic origin containing 9 to 10 pct oxygen are borderline coking coals. The development of an integrated steel plant at Pueblo, Colo., prior to and during World War I, depended on coal of similarly recent origin. Oxygen content was iess than 8 pct, permitting production of large size coke with the advantage of good impact strength, but with the disadvantage of poor abrasion resistance.

Prior to 1923, there were discussions in the industry regarding the possibility of making coke from Utah coal. The question arose as to whether, if Utah coal were used, a blast furnace practice commensurate with then-known practice could be developed. Suffice it to say that pioneers at Provo from 1923 to 1926 did make coke from Utah coal, although some of the men in charge of these early experiments admitted problems. For example, the unagglomerated char occasionally ran like so much sand from the oven doors when they were removed, proof that the coal had not been coked rapidly enough or at sufficiently elevated temperatures.

Coke produced from 100 pct Utah coal, carbonized under optimum conditions, is small in size (most of it passing through a 4 in. screen), as well as weak and friable. The use of eastern operating techniques with such small and weak coke during early furnace practice at Provo was frankly discouraging. Progress frequently results from adversity, and it was at the Provo, Utah, furnace in the mid-twenties, that controlled sizing of ore began through adoption of crushing, screening, and sintering of ore fines. Consequent to these changes and those of modified operating technique, the early Provo furnace performed well, with iron production at, or above the rated capacity and with a coke rate of about 1600 lb per net ton of iron.

Fontana Blast Furnace Design

The succeeding presentation of the development of the Fontana blast furnace design is chronological and follows the discussion of early Provo practices. It is interesting to observe events and people seemingly at a technical impasse, yet eventually arriving at a successful conclusion.

Basic studies for an integrated steel plant in the Los Angeles area were made by Kaiser Engineers in

W. C. RUECKEL is the Manager of the Chemical Div., Kaiser Engineers. This paper was presented at the Los Angeles Annual Meeting of the AIME, February 1953.

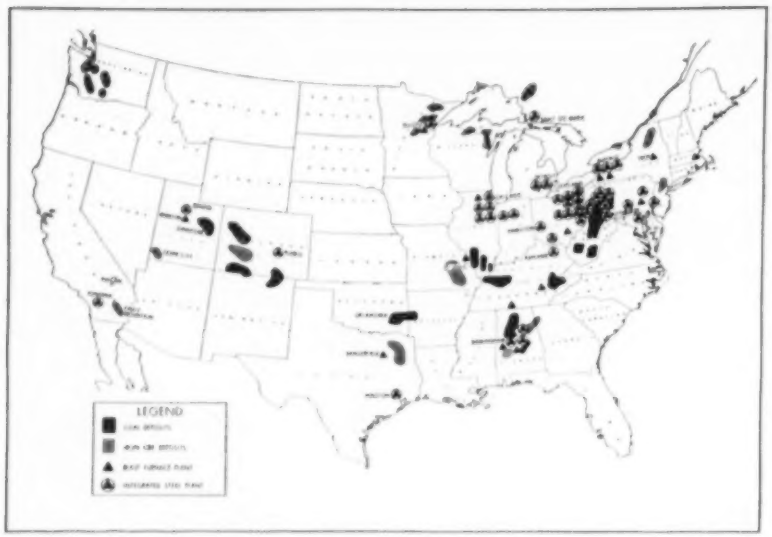

Fig. 2—Locations of blast furnaces, steel plants, coking coal and iron deposits in the United States are shown on this map. Kaiser's West Coast Fontana works can be seen in geographic relation to its raw material source.

1941. Upon approval of the project by the War Production Board, the chief question was not "how to design the blast furnace and the coke plant" but "how soon can steel be made?" Generally speaking, this situation was true of many similar World War II projects but with a major difference: Blast furnace design was of vital importance to Kaiser Engineers, since an RFC loan had been secured through the pledging of Kaiser Steel Corp. assets; an unusual financial procedure for needed war-material manufacture. Because of this, economic production of pig iron during the war became an instrument of survival, the keystone, if you will, upon which was eventually built the post-war competitive position of Kaiser Steel Corp.

Kaiser Engineers was assigned basic responsibility for design, procurement and erection of the Fontana plant. An aerial view of the plant is shown on the front cover.

When approached early in 1942, a leading blast furnace design and construction firm advised that they could not crystallize furnace lines without six to nine months raw materials study, and that the earliest possible furnace operation date would be late 1943. After several weeks of time lost in negotiation with various firms, Kaiser Engineers decided to retain several consultants and design the furnace with its own forces. George Havas, general manager, with the assistance of George Vreeland, chief consultant, William Vogt, project engineer, all of Kaiser Engineers, and with Frank Janicek of Republic Steel, developed and agreed upon basic furnace lines in less than one month, and date for production of first pig iron was Jan. 1, 1943. Basic data and various dimensions of Fontana furnaces (1 and 3) are shown in Fig. 3. By way of interest and comparison, similar data of Geneva and Provo furnaces of Columbia Steel Corp. are presented. The design of Geneva and Fontana furnaces indicates that a large hearth diameter of 25 ft 6 in. was considered workable for furnaces using coke of moderate to weak strength. Major difference in design between these and eastern furnaces is one of furnace height and working volume. The Geneva furnace design, with a height of 93 ft, undoubtedly accepted weak coke as a necessary evil, thereby sacrificing working volume through reduction in height. Crushing of weak coke by weight of superimposed burden is the major concern of designers regarding furnace height. The Fontana furnaces represent only a mod-

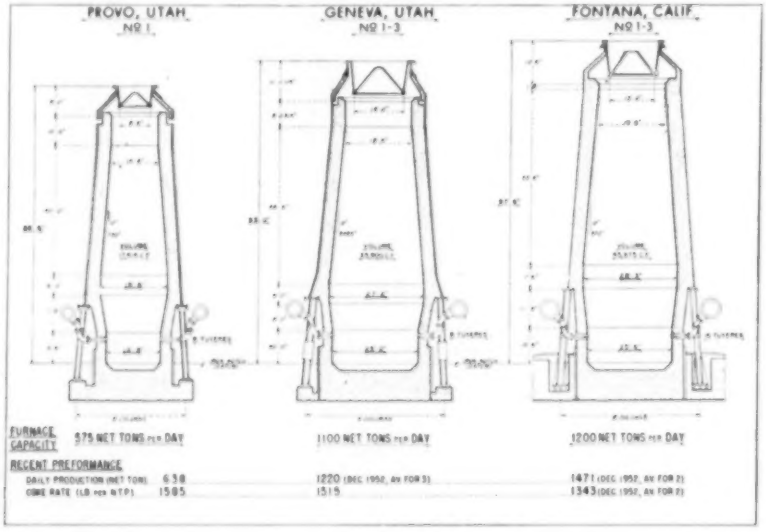

Fig. 3 — Basic data and various dimensions of Fontana furnaces are compared with similar data of Geneva and Provo furnaces of Columbia Steel Corp. Major difference in design between these and eastern furnaces is one of furnace height and working volume.

erate compromise in height, being 97 ft 6 in. high as compared to eastern practice of 105 ft. Further increased volume of Fontana furnaces, however, was created by increased bosh diameter. At first glance, it might appear that Kaiser Engineers design decisions were presumptuous, compared with conservative standards of design accepted by other groups having almost twenty years operating experience. Fontana furnace design, nevertheless, was based on confidence that coke made from Utah coal would be usable in somewhat higher furnaces than those at Geneva. Recent performance data for furnaces 1 and 2 are shown in Fig. 4.

Coal and Coke Research

To improve coke quality, the effect of additions of pitch, low volatile coal and char to Utah coal was studied. The results of a large number of tests are shown in condensed form in Fig. 5. The Physical Fuel Value is a dimensionless number calculated from an empirical formula based on tumbler, shatter and screen tests as well as on porosity. The formula, developed by F. W. Wagner, was published by R. W. Campbell at a meeting of the Chicago Blast Furnace & Coke Oven Assn., Oct. 16, 1936. Difference in reference point value for no addition is due to age of coal samples used in the test.

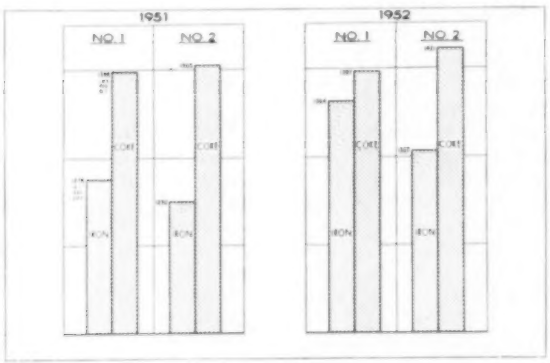

Fig. 4—Recent performance data for Fontana furnaces 1 and 2 show iron production and coke consumption figures.

Most marked are the incremental effects of small amounts of less than 20 pct low volatile Oklahoma coal to Utah coal. Char additions seem to reach an optimum in the 10 to 15 pct range. Additions of pitch seem to indicate an improvement in the same range although pitch usually does not markedly improve the quality of coke but does form an added source of carbon. The maximum amount of pitch available for recycle at Fontana is about 2 pct. It has been Fontana coke plant practice to blend Sunnyside (Utah) coal with about 2 pct recycled pitch and 10 to 12 pct Oklahoma low volatile coal. Weathering of Sunnyside coal and its effects on the physical properties of coke is shown in Fig. 6. Design characteristics of the Fontana plant were carefully planned to provide ease of stockpiling, blending, and reclaiming of coal in order to provide uniform feed stock and a minimum of weathering in storage. The handling system incorporates methods for direct unloading to mixing bins of fresh rail coal, and withdrawal of blended coal from stock with a minimum of weathering. Stocks of Sunnyside coal are kept at a minimum level, consistent with possible interruption in supply, particularly during hot weather.

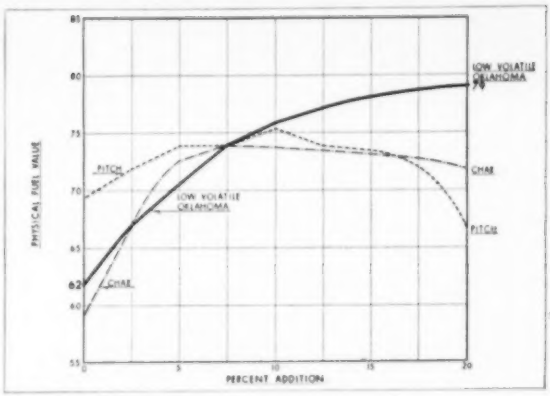

Fig. 5—Results of tests to determine effect of additions of pitch, low volatile coal and char on Physical Fuel Value of Sunnyside Utah Coal are given in condensed form.

It can be noted from Fig. 5 that small amounts of low volatile coal, when added to feebly coking coal, produce disproportionately large improvements in coke quality. Improvement is believed to result primarily from compatible characteristics of the several coals, such as plasticity (devolatilization) and shrinkage.

Coking of 100 pct Utah coal is best accomplished in narrow ovens operated at high temperatures. Accepted practice, when coking 100 pct Utah coal, is to use ovens 14 in. wide and to operate at maximum allowable flue temperature, so that the oven wall temperature after *coke push* is about 2100°F. For comparison, eastern practice generally employs ovens 17 to 18 in. wide and wall temperatures in the vicinity of 1800°F after pushing. When coking straight Utah coal, 50 to 75 pct of the charge adjacent to the oven walls will be formed into fingery coke of moderate strength. Despite the use of narrow ovens and high temperatures, coke at the center of the oven will be pebbly. The term *pebbly coke* is descriptive since it seems to consist of spheres of porous char not completely fused and bonded. The amount of such pebbly coke produced will vary directly with temperature and rate of heating.

Typical plasticity curves for eastern coals are shown in Fig. 7. High volatile, high rank coals of the Pittsburgh and Taggart seam reach maximum

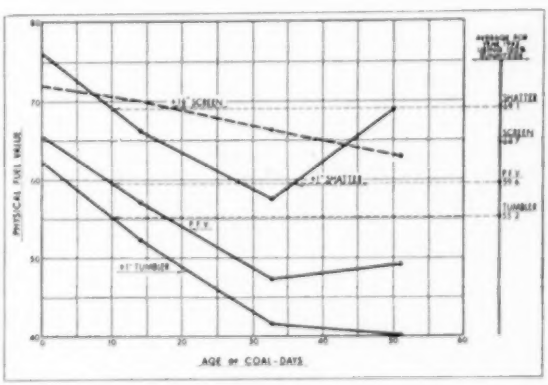

Fig. 6—Weathering of Sunnyside coal and its effects on the physical properties of coke are shown.

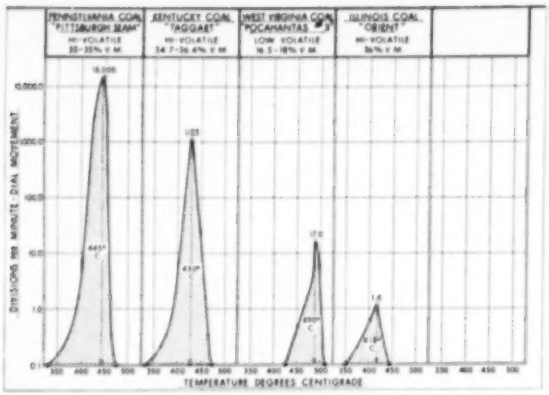

Fig. 7—Curves give typical plasticity values for eastern coals. The large difference in plasticity values can readily be seen.

plasticity values ranging from 1000 to more than 10,000 Gieseler test units. Low volatile coals, of the West Virginia Pocahontas No. 3 type, reach maximum values of about 20. Plasticity curves for various coals used in the plant mix at Fontana are shown in Fig. 8. Maximum plasticity value for the high volatile Sunnyside (Utah) coal is similar to values for eastern low volatile coals and is, of course, far below those of eastern high volatile coals. In fact, maximum fluidity of the plant mix is higher than for Utah coal alone by virtue of additions of medium volatile (21 to 23 pct) Oklahoma coal.

An explanation of the effect of slow rates of heating of Utah coal is that the devolatilization of coal proceeds to the point where it no longer has sufficient fluidity to coalesce the discrete particles of char. The formation of a pebbly seam of coke is also believed to be caused in part by the accelerated oxidation of coal resulting from high temperatures occurring at the center of the charge.

In developing the coke plant practice, now followed at Fontana, experiments were conducted with many different low volatile coals. Considering its size, the Oklahoma coal field is marked by extreme variability. Certain localities, for instance, mine coals ranging in character from anthracite to subbituminous. It is imperative that the proper type of low volatile coal be selected for blending with Utah coal. Assistance in making the proper coal selection can be secured by using a test oven to check incoming shipments before use, and to run frequent plasticity and laboratory tests. The small test oven, if used consistently and intelligently, gives a good approximation of full scale practice and permits detection of poor coals before use so that they can be discarded or used in diluted amounts over extended periods of time.

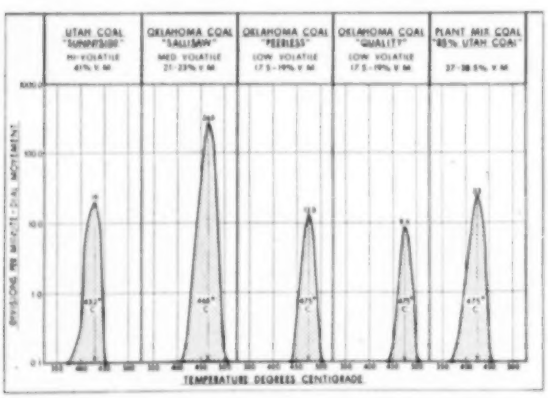

Fig. 8—Plasticity curves for various coals used at Fontana show that the plasticity value for high volatile Sunnyside coal is similar to values for eastern low volatile coals.

Plasticity tests can be particularly valuable, insuring that all coals used in the mix be compatible in melting range and, most important, that the shrinking rates of the several coals used in the mix are similar. The indiscriminate use of low volatile coal may produce discouraging results.

Blast Furnace Practice

Delivery from the coke plant of the strongest, most uniform coke possible, consistent with economics of plant location permits the furnace operator to concentrate on variables of ore analysis, and uniformity of size and chemistry.

Prior to 1949, the Fontana blast furnaces used 44 to 49 pct Fe ore from Cedar City, Utah, and high-sulphur Vulcan (California) ore. Vulcan ore was sintered to reduce its sulphur content by 95 pct.

First large scale test runs of a new Eagle Mountain, Calif., ore deposit were made in 1947. Analysis of the ore in place indicated wide variations in physical and chemical properties. Average analysis of proven ore was 51.2 pct Fe, 0.4 pct sulphur and less than 0.1 pct phosphorous.

In 1948, Kaiser Steel Corp. developed the Eagle Mountain ore property and built a 52-mile railroad from the property connecting with the Southern Pacific Railroad at Ferrum. Shipments of Eagle Mountain ore to the Fontana plant began in the spring of 1949. At Eagle Mountain the ore is mined at several locations to smooth out variations in analysis, assuring more uniform shipments. It is then crushed to 8 in. size, stockpiled and later reclaimed into cars for shipment to the plant.

Fig. 9 indicates, in diagrammatic form, the flow of materials through the blast furnace plant at Fontana. Incoming lump ore is crushed in a jaw and cone crusher, and screened to a maximum size of -1 in. by $+\frac{3}{8}$ in. for direct addition to the furnace. Ore is stocked and reclaimed by a bedding system to equalize variations in ore analyses and physical size, and to insure feed of pre-analyzed ore to the furnace bins.

Too much emphasis cannot be placed on the soundness of the basic design of the Fontana plant. Ample flexibility was provided in all elements of crushing, screening, stockpiling, sintering and conveying of raw materials. This flexibility is responsible for the successful operation of the plant which, in 10 years, has used three widely differing types and qualities of ore.

The first and early practice was based on 100 pct Vulcan ore, crushed to 2x2½ in. top size, the fines being sintered primarily for purposes of sulphur reduction with agglomeration being a further advantage. The second phase began with the use of Utah ore. At that time sizing was also varied to produce optimum results with a furnace feed consisting of 45 pct coarse Utah ore and 55 pct Vulcan ore and sinter. The third phase began with the introduction of Eagle Mountain ore. As mentioned above, Vulcan ore had been crushed in the first phase to 2½x2 in. Experience proved, however, that best results with Eagle Mountain ore could be obtained with 1 in. top size. In addition, the $-\frac{3}{8}$ in. fines of Eagle

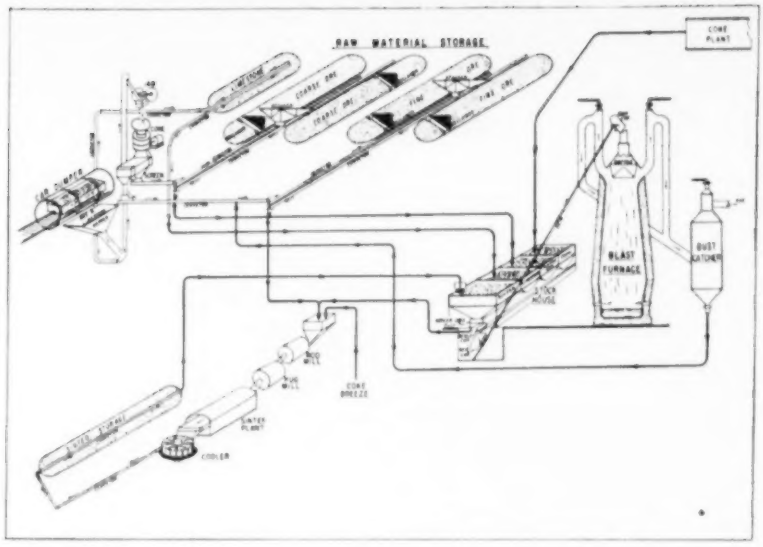

Fig. 9 — This diagrammatic view of the blast furnace plant at Fontana shows the raw material flow. The flexibility provided in all elements of crushing, screening, stockpiling, sintering and conveying of raw materials is responsible for the successful operation of the plant, which has used three different types of ore in the last 10 years.

Mountain ore had, at most a sulphur content of 0.4 pct, in contrast to Vulcan ore, used in the second phase, which had a sulphur content of 1 pct or higher. Throughout the period of its exploitation, the sulphur content of the Vulcan mine consistently increased with depth. This phenomenon is common to all Southern California ore bodies.

A glance at Fig. 9 will show that $+\frac{3}{8}$ x $-$ 1 in. coarse ore and $-\frac{3}{8}$ in. fine ore are being stocked separately. The coarse ore is reclaimed directly from the bedding system for charging to the furnace. Fine flue dust from the furnace is stocked with the fine ore and the combined materials are reclaimed as sinter plant feed.

At present, the sinter plant consists of a 72 in.x 102 ft 2 in. Dwight Lloyd machine with sufficient capacity to sinter approximately 36 pct of the ore requirements for the operation of two furnaces. A second sintering machine is being installed so that approximately 40 to 45 pct of the ore for the furnaces will be sintered when the third furnace (see Fig. 1) is placed in operation late this year. At this point it should be mentioned, however, that experiments were made prior to the design of the plant, which led to the conclusion that fine grinding of the ore is not necessary but that sinter of $-\frac{3}{8}$ in. will yield adequate results.

Coke breeze, added to the sinter, is ground in rod mills to $-\frac{1}{8}$ in. size. Coke, flue dust and fine ore then are mixed and conditioned in a pubmill prior to introduction to the sinter bed. Before stocking, sinter discharge is cooled in a novel atmospheric type cooler developed and patented by Fred Greyson of Kaiser Engineers. Before concluding the description of material flow to the blast furnace, it should be noted that oven coke is screened at only one point below the furnace bins, before being added to the furnace. This insures delivery of uniformly sized coke to the furnace, and greatly reduces degradation.

Stocking and Reclaiming

Fig. 10 shows Fe and sulphur analyses of ore before and after stockpiling and reclaiming from the bedding system. Improvement in uniformity of analyses can be noted for Fe and sulphur content, although sulphur improvement is more marked.

A significant result of the bedding system is the smoothing of wide shifts in analyses, which give the furnace operator time to adjust his furnace burden and enables him to provide more uniform ore feed.

Ore Sizing

A number of studies have been made at Fontana of the effect of ore sizing on furnace operation. The data presented in Fig. 11 are for a period shortly after No. 2 furnace was blown in. During the test period, a transition was made from use of Vulcan and Utah ore to straight Eagle Mountain ore.

Starting on Nov. 15, 1950, the average particle size of the ore charged to No. 2 furnace was increased and, as can be noted, hot metal production *decreased* and coke rate increased proportionately. In a very short time it was found that, as average particle size of charged Eagle Mountain ore was decreased, furnace practice improved. The test data proved, in fact, that Eagle Mountain coarse ore should be crushed to a smaller size than Utah ore.

Later, two separate test runs of one month duration were made on Eagle Mountain ore. In each of these, maximum ore size and percent sinter were varied. The results of the tests are shown in Table I. The data indicate the benefits of small 1 in. ore over 1½ in. ore despite reduction in sinter. Since no Utah ore was charged to the furnace during or

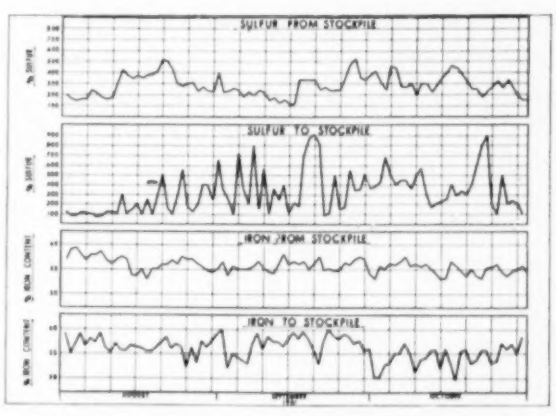

Fig. 10—Improvement in uniformity of analyses for Fe and S content of ore resulted from ore bedding.

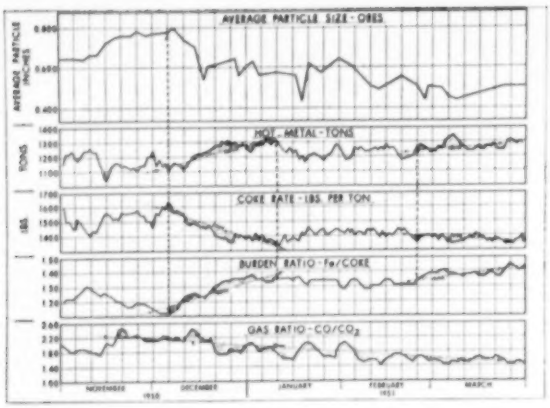

Fig. 11—In the study of the effect of ore sizing on furnace operation, it was found that furnace practice improved as average particle size charged decreased.

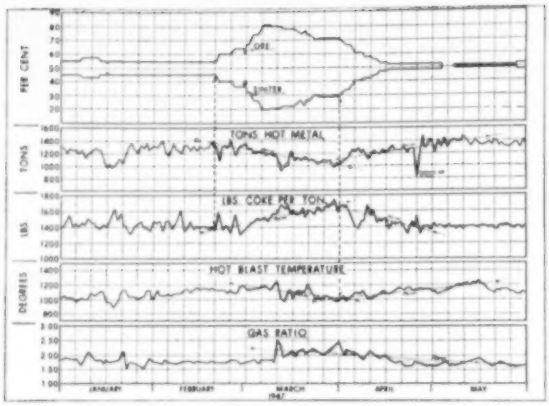

Fig. 12—Increased sinter content resulted in improved hot metal production and coke rate. Development and use of an atmospheric sinter cooler contributed to improved furnace practice.

at any time after test period, the true effect of properly preparing and sizing Eagle Mountain ore is clearly proven.

Sinter Practice

It has been demonstrated at Fontana that increased sinter content improves furnace practice by *reduction* in fines and sulphur content of the charge. The preceding data on sizing indicate that furnace practice improved through reduction in average ore size despite reduction in sinter. As was previously mentioned, sinter capacity at Fontana is being doubled to permit use of 40 to 45 pct sinter, when third furnace is blown in, rather than 36 pct. This fact indicates its value. Unfortunately, plant operations since introduction of Eagle Mountain ore have not permitted full scale furnace tests with increased sinter. However, experiments conducted during past years led to the conclusion that a sinter charge of 75 pct is practicable. The effect of sinter content on furnace practice, shown graphically in Fig. 12, is for the period of January to May 1947 when Utah and Vulcan sinter was charged to the No. 1 furnace. Improved hot metal production and coke rate are clearly shown as resulting from increased sinter content. The development and use of an atmospheric sinter cooler at Fontana has contributed measurably to improved furnace practice. This is true particularly through a reduction in the percent of fines ($-\frac{1}{8}$ in. size) generated in the sinter plant.

The preceding discussion has outlined the evolution of a highly successful blast furnace practice at Fontana, despite the use of coal which until recently was not thought to have good coking qualities. In view of the progressive depletion of our natural resources of conventional coking coals, it is hoped that some of the concepts developed in the evolution of the Fontana practice may assist other coke consumers by broadening the field of usable coals.

Summary of the more salient points of the Fontana practice are:

1—Marked improvement in coke quality through addition of small amount of low-volatile coal to feebly coking coal, is believed to result from compatible plastic, devolatilization and shrinkage characteristics of the several coals.

2—Uniformity of furnace burden materials has resulted from improved stocking and bedding systems for coal and iron ore.

3—Controlled sizing of all materials charged to blast furnace has produced smooth furnace operation and high production rates.

4—Sintering of ore to reduce fines and sulphur content of burden has improved furnace practice.

5—Flexibility in plant layout has permitted development of successful practice with widely differing types of ore, and resultant wide differences in furnace practice.

6—Courageous furnace design was based on confidence in ability to produce improved coke. This in turn permitted the attainment of an outstandingly successful furnace practice with savings in capital and operating costs through increased production.

7—The increased working volume of Fontana furnaces, combined with increased reducibility of small size ore, has resulted in low coke consumption rates per ton of iron produced.

8—Low blast volume per ton of iron is the consequence of low coke rate and the high indirect reduction of the ores by the gases in the stack of the furnace. This is the result of careful ore sizing which insures uniform distribution of the gases throughout the entire volume of the furnace.

9—The blast rates per ton of iron have resulted in moderate to low rates of flue dust produced.

10—In 1952, the two blast furnaces at Fontana produced a daily average of 1335 tons of pig iron per day on furnaces rated at 1200 tons per day.

11—In 1952, the two blast furnaces at Fontana, while making the cited pig iron production records, consumed an average of 1409 lb of coke per net ton of iron produced, compared to a national average of 1600 to 1700 lb per ton.

12—Operating personnel at Fontana merit acknowledgment for excellent performance records.

Table I. Effect of Ore Size on Furnace Operation

Operating Data	Period 1	Period 2
Maximum Ore Size, In.	$-1\frac{1}{2}$	-1
Average Particle Size	0.725	0.472
Eagle Mountain Ore, Pct	50.0	57.7
Eagle Mountain Sinter, Pct	50.0	42.3
Fe, Ore and Sinter, Pct	55.91	56.42
Average Tons Per Day	1167	1330
Average Coke, Lb Per Ton	1579	1358
Average Fe/Coke in Charge	1.19	1.43
Average Blast Temperature, °F	1337	1260
Average Gas Ratio CO/CO_2	2.22	1.42

Beneficiation of East Texas Iron Ores Basis of Lone Star Steel Operations

by W. R. Bond

THE success of the Lone Star Steel Co. and its blast furnace operation at Lone Star in East Texas has resulted from the partial solution of the problem of concentration and beneficiation of East Texas ores. It is necessary to emphasize *partial solution*, for the company has learned a great deal about these ores in the five years operations have been in progress, and more is being learned every day. In addition, several long range studies have been started that will improve knowledge of the ores, and it is hoped, indicate improved methods of beneficiation that will in time bring the complete solution nearer.

Although there had been some exploitation of East Texas iron ore at various times during the preceding century, none involved the volumes required by the Lone Star operation, so that there was no practical previous experience to serve as a guide. Only the close proximity of the blast furnace to the ore mines and beneficiation plant, and the close and complete cooperation between the men at the furnace and at the ore operations, developed the experience which insured the company's success.

The iron ores of East Texas occur in two distinct areas in the northeastern part of the state. These two districts are commonly referred to as the North and South Basins. The North Basin, in which the majority of Lone Star Steel Co.'s ore holdings are located, is mainly high land located between the Sabine and Sulphur Rivers and extending west from the Texas-Louisiana border for approximately 60 miles in a belt about 25 miles wide.

The ores in the North Basin occur as a flat lying bed, in or near the tops of hills. The balance of the original formation was probably eroded away by the action of streams and rivers. Both the North and South Basins were probably a continuous formation at one time. Now they are separated by the Sabine River Valley.

For those geologically inclined, the formation is the Weches member of the Mt. Selman formation. It is flat, or low dipping to the southeast, and is of the Middle Eocene Age. The formation lies upon the Queen City Sand, this being composed of alternate layers of white sand and clay of varying thickness. The ore formation is covered in the highest hills by a very soft Sparta Sand, which is composed of fine sand and soft clay. It is believed that this formation was laid down some distance out in the prehistoric predecessor of the Gulf of Mexico as a bed of glauconite sand interspersed with layers of plastic clay and other sand.

Evidence points to a concentration of varying degree in the formation into layers of clay, sand, and gray iron carbonate (siderite). These occur as non-continuous seams, plates, nodules, and other shapes with the clay being changed to a shale which is very plastic, greasy, and impervious to chemical or physical action.

During the geologic development of this area, in which time erosion formed valleys, and incidentally carried away a considerable part of the iron ore, the remaining areas were enriched through the action of descending oxidizing water. The oxidation changed the carbonate to a hydrated oxide of iron known as limonite. This limonite occurs on the out-crops and around the edges of the hills where the lack of overlying material allowed the water free access to the formation. Wherever it is possible for water to percolate down through the ore bodies, there is some occurrence of limonite in the center of the hills. In most cases, the carbonate siderite remains in the centers of the hills and below the water table.

The natural occurrence of these ore bodies includes an overburden material consisting of sand and clay with occasional thin patches of ferruginous sand stone attached to the limonite ore. The thickness of this overburden averages 4 to 5 ft and ranges from a few inches to 20 ft. The limonite ore itself has an average thickness of about 9 ft and ranges from nothing to 45 ft. The physical structure of the limonite varies from a dense material to a porous cellular structure interspersed as nodules in a clay or sandy bed.

The siderite ore lies below the water table and underneath the limonite ore. It will vary in thickness from nothing to 65 ft and averages about 20 ft. It is heavier and more uniform in structure than the limonite and occurs in a clay-sand matrix of considerable density which is most difficult to free from the ore. This point will be discussed in detail later.

South Basin ores are located south of the Sabine River Valley which separates the two basins, and are generally north of the Noches River. The hills that contain these ore bodies are centered in Cherokee County and are about 35 miles in length and about 20 miles in width. The ore in this basin is of a solid ledge type, being dense in structure and varying in physical characteristics from a buff crumbly condition to a dense, solid mass. These ores vary somewhat in thickness, from 1 to 3½ ft, and occur under an overburden which varies from very little to 25 ft. As the Lone Star Steel Co. has not mined any of these ores, they will not be considered further here.

W. R. BOND is Vice-President in Charge of Operations for Lone Star Steel Co., Lone Star, Texas. This paper will be presented at the Blast Furnace, Coke Oven, and Raw Materials Conference, Buffalo, N. Y., Apr. 20 to 22, 1953.

During the past 100 years or so, several attempts were made to utilize the East Texas ores for the production of pig iron. While it was demonstrated that iron could be produced, none of the operations were economically successful primarily because of the small size of the operation and the considerable distance from the blast furnace to the centers of manufacture in which the iron was sold. These factors and freight charges priced East Texas iron right out of the market.

A known total of 10 small furnaces operated in East Texas at various times, only two of which lasted for any considerable period. These were the operations at Kellyville, and the State furnace at Rusk which was operated with convict labor. The ore used for these small operations was concentrated by hand sorting and was smelted with local charcoal as fuel. It is interesting to note that during the War between the States several furnaces were operated, or subsidized, by the Confederacy for the production of iron for the war effort.

History repeated itself when the Federal Government, during World War II, through the Defense Plant Corp., financed the construction of three blast furnaces for use of the East Texas iron ores. One of these furnaces is located at Houston, one at Rusk, and the third is the well known *Flossie Belle* of Lone Star Steel Co.

The principal ore holdings of Lone Star are in Morris, Cass, Marion, and Upshur Counties in the North Basin in the vicinity of Daingerfield, Texas. These ore bodies are within a radius of 20 miles of the ore beneficiation plant, which, in turn is but 3 miles from the blast furnace itself. The beneficiation plant was constructed as a part of the facilities erected in conjunction with the blast furnace, and was operated for two short periods during 1944 and 1945 producing ore for the market. Satisfactory concentrated and calcined ores in some quantity were produced at these times but the operation was uneconomical because of the freight charges from East Texas to the nearest furnaces.

In 1947, the Lone Star Steel Co. was reorganized and leased the blast furnace and other facilities from the War Assets Administration. The plant as it then existed, consisted of one 1200-net ton capacity blast furnace; a battery of 78 Koppers-Beckers coke ovens capable of producing 1250 net tons of coke per day; coal mines producing medium and high volatile coal, which are located in Oklahoma, near McAlester, approximately 250 miles by rail from the main plant; an electric power generating plant; extensive ore properties, and a beneficiation plant.

In 1948, this plant was purchased outright and has been successfully operated since that time making high quality pig iron from a burden of 100 pct East Texas iron ores.

Other developments in the company's history include the erection of a foundry for the manufacture of cast iron pressure pipe by the centrifugal process, which was placed in operation in 1950, and the current erection of steelmaking, rolling, and finishing facilities which will give the company a completely integrated operation. Part of these steel facilities are in operation now.

The economy of this whole enterprise is based, as with any large operation, upon raw materials. So, at Lone Star the iron ore, which is converted into hot metal and then into steel, is viewed as the basis of the company. It is believed that the success achieved in the past in the beneficiation of these ores is now, and that which may be had in the future has, and will be, the measure of success as a company.

The blast furnace is a reducing apparatus. Any gangue material other than enough to provide the necessary slag volume for smooth operation should not be present in the ore being charged. While considerable progress in beneficiation of ores has been made at Lone Star, the job is not complete and to that extent, the blast furnace is assuming part of the job of concentration. Waste material is being introduced into the furnace which, in the future, will be eliminated outside of the furnace. So, in the discussion of the beneficiation of East Texas ores, there is often reference to the effect of the method of concentration on the furnace operation, and vice versa.

The crude limonite ore available for concentration is widely scattered in comparatively thin layers over an extended area on top of the hills. It analyses in the ground 21 to 28 pct Fe, with from 45 to 65 pct silica, and concentrates to a grade of 41 to 44 pct iron, at ratios of from 2½:1 to 5:1.

The crude siderite ore, as it occurs in the ground, analyses 17 to 28 pct Fe, with from 35 to 55 pct silica, and 15 to 22 pct alumina, with concentration ratios of from 3½:1 to 10:1 when beneficiated, by washing, to a grade of 40 to 42 pct Fe.

So far the average feed to the mill has been about 23 pct Fe. This is some of the lowest grade iron ore used in this country today. The washed limonite, containing 41 to 44 pct Fe, will carry 19 to 22 pct silica. The washed siderite, containing 40 to 42 pct Fe will carry about 12 pct silica.

Mining is relatively simple. The overburden, which averages 5 ft is light and easily removed with scrapers and deposited in the valleys. The ore is loaded, without blasting, by draglines which operate on top of the formation so the receiving trucks will not have to enter the pits and be hampered by the mud and clay present there and on the top of the siderite during the wet season.

Transportation is one of the major problems. From 2½ to 10 tons of material must be hauled to get 1 ton of finished ore, and hauls range from 1½ miles to 12 miles in length. At present, Euclid 15-ton units and one Mack 35-ton unit are used on the shorter hauls. The company contracts with owners of standard commercial dump trucks for deliveries on the longer hauls. The larger units operate over roads constructed and owned by the company. The contract trucks operate over state and county owned roads. As a direct result of transportation experience, a rear dump tractor-trailer truck is being developed which will haul any distance with a payload of 50 long tons at 35 to 40 mph, on level road. Results are encouraging.

The original mill, built by the Defense Plant Corp. under pressure of war, without previous operating experience and knowledge of the problems involved, other than through testing and pilot plant work, was basically a super gravel washing plant. It contained two units in parallel, one for limonite and one for siderite. The flow sheet is shown in Fig. 1.

With the above plant, it was only possible to wash the best grades of crude ore, at a low rate of feed, for a satisfactory concentrate.

This original plant also contained a 300x11½ ft rotary kiln (gas fired) and 125x11½ ft cooler, for the calcination of siderite to hematite. It also contained a Dwight-Lloyd sintering machine, 110x5 ft

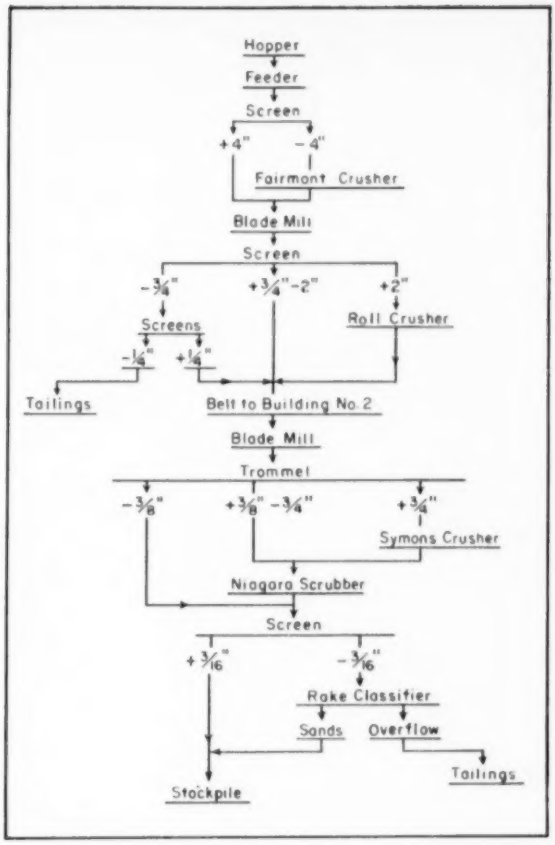

Fig. 1—In the original mill, it was only possible to wash the best grades of crude ore. The Fairmount crusher used was single roll with teeth. In the 9x18 ft blade mill, sometimes called scrubber, ore and mud were tumbled with water. The ore chunks were expected to beat up and dislodge the mud, and to a certain extent they did. The Niagara scrubbers were screens with pockets about 15 in. wide and 18 in. deep that ran across the screen frame, being fed on one side and discharged on the other. These were to scrub by rotary action, but in the case of this particular sticky ore it can be said that had the world been searched for a mud ball maker, a better device could not have been found. After screening, the 3/16 in. product was a finished washed ore. The —3/16 in. material was fed to rake classifiers for separation at about 20 mesh.

for sintering the fines. There also was a heavy media separation plant in the original setup.

In the first two attempts to operate this plant, for four months in 1944 and five months in 1945, the crushing and washing plant and the kiln were operated primarily on siderite ore with unsatisfactory results and high costs.

On Oct. 13, 1947, the ore mines and ore plant were started and on Oct. 25, 1947 the blast furnace was blown in using 100 pct East Texas ores. An ore plant was started on October 13, which, in previous operation, had produced an average of about 900 tons per 24 hr and on October 25, with 5400 tons on the stockpile, a blast furnace was blown in which needed 1800 to 2400 tons of ore per 24 hr, and the ore plant was expected to feed this furnace. It could only happen in Texas.

By using the best grade of crude limonite, with minor changes in screen sizes; the elimination of the Niagara scrubbers, and by putting water in the Symons cone crushers, it was possible to get the ore plant production up to about 2500 tons of concentrates per day of 42 to 44 pct Fe with insolubles of 22 to 25 pct.

This material was fed to *Flossie Belle*, the furnace, and quality pig iron was produced. Natural moisture, together with the water of hydration in the limonite ore, resulted in a low furnace top temperature. Because of this water of hydration, the ore exploded in the furnace, causing dust to precipitate out of the gas and collect in a mucky condition in the dust catchers, gas washer, and precipitator. It made a mess and was difficult to remove. To tide the company over during this break-in period in December 1947 and January 1948, when initial changes were being made in the ore plant, and because of wet weather, some outside ore was purchased. Part of it came from Utah, some from Missouri, and some from the Mesabi Range. However, at least 75 pct of local ore was on the furnace at all times.

Because of the large percent of washed limonite used, coke rate was unsatisfactorily high, being 2600 to 2800 lb of coke per gross ton of iron.

In January 1948, an idea was conceived of dehydrating or calcining the limonite in a rotary kiln to dry it and drive out the water of crystallization and thus raise the grade. This had never been done. It was said that this operation would reduce the limonite ore to dust; however, laboratory tests indicated it would work, so on Jan. 12, 1948 the kiln was started and heated the washed limonite to 1100° to 1400°F.

The limonite did not disintegrate but simply changed to a porous hematite and the grade was raised from about 42 pct Fe to 47 pct Fe. The silica and alumina remained about the same, because of the draft in the kiln carrying away fine sand and clay as dust. There actually was about 6 to 7 pct silica elimination in the kilns.

This operation is probably the most important step in the beneficiation of East Texas iron ores to make them economical for 100 pct use in making pig iron. Following this discovery, an additional kiln was installed, which eliminates operational delays and makes it possible to run, at choice, limonite or siderite through either kiln. This is very important because the *ringing* of the kiln from siderite can be controlled by changing the siderite to limonite. The temperature is lowered, thereby contracting the ring, and it removes itself.

Siderite ore is calcined at between 1700° to 1900°F. The kiln operation not only removes natural and chemically combined moisture but removes by oxidation a large portion of any sulphur in the ore. The Dwight-Lloyd sintering machine was rigged with a hood and long flame burner and used to dry and dehydrate limonite. This was a unique operation but the fan did pull the flame down through the bed and do a partial job of drying. For both the kiln and sintering plant operation, either natural gas or coke oven gas was used.

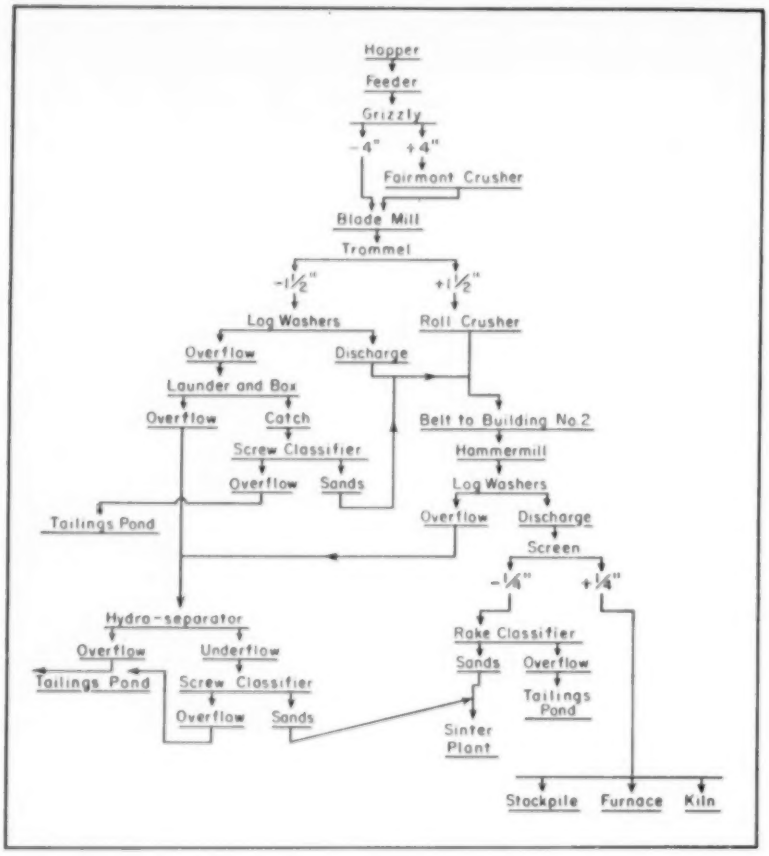

Fig. 2—Starting in 1948, many changes were made in the ore plant until the present flow sheet shown was realized. Better washing conditions were obtained by eliminating all double deck or double trommel screens and adding high pressure water to stop mud build up. Log washers replaced blade mills in the secondary washing plant, and then replaced tailings screens in the first stage of washing. A hammermill was substituted for the Symons cones which had a tendency to plug. A Hydroseparator was also added to aid in recovery of fines tailings. Future plans call for a heavy media installation in the mill.

During work in dehydrating the limonite in the sintering plant it was found the top 2 in. of the bed sintered easily. Coke breeze was then added, about 9 pct by weight, and the ore sintered. It should be noted that until kiln capacity was increased, the sintering plant feed at this point was + 20 mesh up to − 1¼ in. material which sintered after a fashion. However, the product behaved satisfactorily in the furnace.

The next step was obvious. Concentrates were screened at + and − ¼ in. with the coarse ore either sent direct to the furnace or fed to the kiln for dehydration and the fines (− ¼ in.) sintered. This change was made in April 1948, and the practice has continued up to the present time with but a few minor changes, mainly to increase capacity.

During this period, the furnace was on 100 pct dehydrated ore and as a result, obtained very high top temperatures on the furnace. Insufficient blower capacity was an additional handicap. This situation has been corrected as there is now a 100,000 cfm blower. Various experiments were tried, using different proportions of dehydrated, calcined, washed, and sintered ore on the furnace burden. First, water was added to the charge, but after experimenting with varying amounts of raw washed limonite, the final burden was 75 pct dehydrated ore and 25 pct crushed and washed ore. This maintained production, gave a satisfactory top temperature, and resulted in a savings of approximately 600 lb of coke per ton of iron.

During 1948 and early 1949 minor changes were made in the ore plant. All double deck screens or double trommel screens were eliminated and high pressure water was added to stop the build-up of mud at various points in the mill. This resulted in better washing conditions.

In December 1948 the heavy media plant was started up. After about 4½ months of operation in various ways, including the use of ferrosilicon, magnetite and even the magnetite of flue dust as a media, it was closed down because of the high iron content in the float product. The variation in specific gravity is such that unless there is some further method of concentration on this float, the operation, as it was then positioned in the mill, was uneconomical. Future plans call for a heavy media installation at a different spot in the mill.

Numerous attempts were made during this period to wash the crude siderite but with little success. This was probably caused by the lack of scrubbing capacity. In late 1949 the program was continued to improve the ore plant, and in various steps added log washers of company design. Blade mills were replaced with these log washers in the secondary washing building and successful results were achieved.

Next, log washers added to replace the tailings screens in the first stage of washing resulted in better separation, much better scrubbing and washing, and an additional recovery of fine material. It is felt that there is no substitute for log washers in the operation because of their scrubbing action.

Along with the installation of log washers the third stage of crushing by Symons cones was eliminated, as they had a tendency to plug, and a hammermill substituted at the head of the secondary plant before the final log washing. This was defi-

nitely an improvement as the hammermill tears up the mud, shatters the compact sand, and does not make too many fines if run without grate bars.

Also, in the siderite crude there are varying amounts of unaltered green-sand which are too compact to be abraded by the logs or powered by the roll crushers. This is a complex iron aluminum silicate which is difficult to reduce in the smelting operation and thus causes trouble in the furnace. The impact of the hammermill shatters this green-sand and it can be eliminated as sand in the log washers. Later it is contemplated to recover a portion of this material by magnetic roasting and separation.

With these improvements it was possible to increase capacity and at times to handle as much as 30 pct of feed as crude siderite.

The next step was for the recovery of fines tailings. Although this work is far from the ultimate goal, an additional 400 tons of acceptable material is being recovered from the overflow of the log washers in both stages of washing.

These tailings from the logs are fed to a launder with a settling box below the launder which traps the tramp oversize as well as the heaviest fines and feeds then to a screw classifier. The sands from the classifier are returned to the circuit between the first, and second stage of washing. Much of it is cleaned up and recovered as a final concentrate in the second stage of log washing.

The balance of the log overflow is fed to a 50 ft Hydroseparator and the overflow of this is a final tail. The underflow is pumped to a screw classifier which scalps off the cream as fine concentrates to be sintered. These recovered fines are lower in grade than the general concentrates and this recovery is varied from 6 to 10 pct of the total to take what can be handled. Flow sheet for the new process is shown in Fig. 2.

An idea of tonnages and grades, taken from the October 1952 monthly report, is given in Table I.

This represents a production of 1.64 tons of sinter per sq ft of hearth area and a wet feed of 2.1 tons per sq ft of area. Considering that there is 12.6 pct moisture plus about 13 pct water of crystallization and some CO_2 in the feed, it is felt that this is a satisfactory operation.

Looking into the future, there is a unit designed for washing of siderite now in final design stages. It will consist of a feeder, grizzly, larger hammermill for primary crushing, two stages of log washing, secondary crushing by hammermill and two more stages of log washers. Experience indicates that this will wash and concentrate any of the ores including the most sticky crude siderite.

Various tests also have been run on the magnetic roasting and magnetic concentration on portions of tailings, the float from heavy media separation in both limonite and siderite and on lower grade crude ores. All tests indicate the materials are roasted easily and easily separated by magnetic separation at a relatively coarse size and that a finished product can be made with an iron content above 50 pct. With a good cheap source of gas for this operation, as is available, there is quite a future in this process. With this process available to retreat the reject, a heavy media plant could be used to raise the grade of the washed product.

So far only the operation of the Lone Star plant has been discussed. There are four other smaller plants for crushing and washing limonite only in operation on East Texas ores. All are very similar to the Lone Star operation but carry the process only through the washing stage and make a concentrate higher in grade as they discard most of the fine ores. Two of the plants field screen the crude ore at 2 in. before hauling it to the washing plant. Naturally these other plants have a lower weight recovery and much lower iron recovery.

Table I. Tonnages and Grades Handled, Taken from Report of October 1952

		Iron, Pct	Insolubles, Pct
Crude Ore Feed, Tons	242,433	25.89	50.35
Crushed and Washed Concentrates, Tons	84,862	43.91	23.02
Tailing, Tons	157,571	18.71	61.26
Weight Recovery, Pct	35.00		
Iron Recovery, Pct	48.32		
Silica Elimination, Pct	83.16		
Feed to Kiln, Tons	35,071	44.40	22.16
Calcined Ore, Tons	31,498	48.17	23.06
Weight Recovery, Pct	81.21		
Iron Recovery, Pct	97.69		
Silica Elimination, Pct	6.27		
Feed to Sintering Plant, Tons	17,254	42.17	25.96
Sinter Produced, Tons	15,529	46.72	29.35
Weight Recovery, Pct	78.84		
Iron Recovery, Pct	99.84		

In the use of these East Texas iron ores in the furnace, it is interesting to note they are easily reduced after being beneficiated by the process described and thus the furnace rated at 1200 net tons per day at 50.50 pct Fe and 12 pct silica is steadily producing in excess of 1150 net tons from an ore containing 44 to 47 pct Fe and 18 to 22 pct silica. This is possible because of the porosity of the ore and the preparation it receives in the kiln, both of which make it easy to reduce, and because of the use of 20 to 25 pct of sinter which is helpful in most any blast furnace operation.

Burden on the furnace for some time has consisted of the following:

25 pct Crushed and washed limonite
25 pct Sinter
50 pct Dehydrated and calcined limonite and siderite

The dehydration of the limonite, calcination of the siderite, the use of a high percentage of sinter, and the changes which were made in the present washing process enabling large tonnages of low grade materials to be handled in a given time, the reclaiming of fine materials up to the amount that can be economically used, based on grade, have made possible the use of East Texas iron ores. If improvements in the concentration process can be continued, a vast amount of low grade iron ore will be made available to the steel industry, all of which is within the borders of the United States. The use of these ores opened a new era to a large section of Texas which heretofore has been primarily a nonindustrial area.

The contributory efforts of the following individuals in the solution of the foregoing problems in the beneficiation of East Texas iron ores is respectfully acknowledged: R. E. Crockett, consulting engineer; W. L. Kendrick, div. superintendent, ore mines and beneficiation plant, Lone Star Steel Co.; and A. B. Drescher, formerly chief mining engineer and geologist for Lone Star Steel Co.

Manganese From Open Hearth Slag Could Supply Half of U. S. Needs

by R. C. Buehl, M. B. Royer, and J. P. Riott

EXTENSIVE pilot plant tests on the recovery of manganese from open hearth slag were completed recently at the Bureau of Mines, Pittsburgh, Pa. A cooperative project sponsored jointly by the American Iron and Steel Institute and the Bureau, this work demonstrated that open hearth slags can be treated to yield a synthetic high grade ferromanganese ore. The process developed was described in two recent papers.[1,2] It consists of a two-stage treatment: Reduction of open hearth slag in a blast furnace to produce a spiegeleisen containing 12 to 24 pct manganese followed by selective oxidation of manganese from this spiegeleisen in a basic converter to produce a slag which contains 55 to 60 pct manganese. The Defense Materials Production Agency has signed a $1.25 million contract with Mangaslag, Inc., for construction of a plant which is expected to produce 1000 tons of ferromanganese monthly from open hearth slag by this process.[3]

The unique feature of the selective oxidation operation in the converter involved a recycling treatment of both metal and slag. However, the commercial feasibility of this process could not be evaluated because the 500-lb converter used in the initial trials suffered disproportionate heat losses. Therefore, a 2000-lb converter patterned on the bessemer shape has been constructed.

This converter, pictured in Fig. 1, is surface blown and is similar in design to the surface blown hearth described by Sims and Toy.[4] Three tuyeres enter at one side and blow downward at an angle of 6.5° to the bath surface when the converter is vertical. Originally, five tuyeres were installed but the two end ones were sealed when the maximum compressor capacity of 600 cfm at 23 psi proved insufficient to keep all tuyeres open. Reaction temperature is regulated by introducing either oxygen or steam into the blast as required. The rammed magnesite lining tended to build up in service except for a small area above the tuyeres which eroded enough to require a hot-patch every dozen blows.

An induced-draft fan draws fume and gases from the converter operation into a tight fitting hood thence through a duct to a dry cyclone cleaner, the fan itself, a wet scrubber, and out the stack. Excess air is drawn into and cools the hood and also burns the CO from the converter. Gas temperatures ran as high as 1300°F in the duct during the period of rapid carbon elimination. The dry cleaner is composed of 16 centrifugal separators in parallel. The scrubber is also centrifugal in action. Fume was distributed as follows: Dry cleaner, 40 to 60 pct; wet washer, 15 to 25 pct; lost up stack, 25 to 35 pct.

R. C. BUEHL is Chief, and M. B. ROYER and J. P. RIOTT are Metallurgists, Ferrous Pyrometallurgy Section, Bureau of Mines, Region VIII, Pittsburgh.

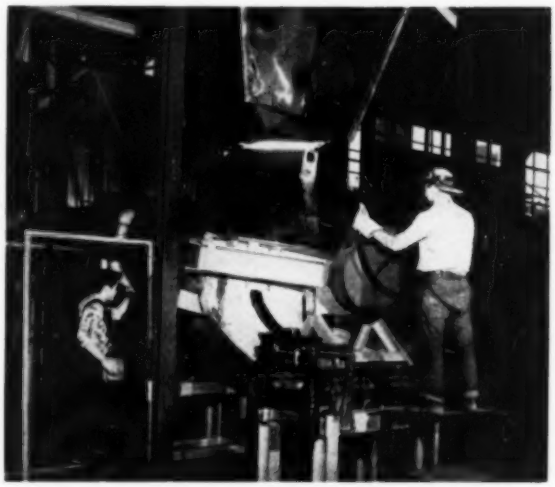

Fig. 1—A one-ton experimental side-blown, basic-lined converter was used for the selective oxidation of manganese from spiegeleisen.

Fume leaving the stack was very fine, more than 95 pct of the particles being smaller than 1 micron. Consequently, the stack discharge appeared dense although the weight of fume was as little as 0.2 lb per min. Fume emission was controlled more effectively by adding steam to the air blast than by scrap or ore additions to the converter. Fume loads of 2.4 grains per cu ft could be decreased to 0.6 grains per cu ft by such steam additions.

As shown in Fig. 1, the converter is mounted on scales so that weights may be taken at any stage in the blow. Both converter and gas cleaning plant are completely instrumented.

The problem had been to produce high manganese slag product having a phosphorous content no greater than 0.2 pct from spiegeleisen containing 3 to 4 pct phosphorous. Slags of the prescribed phosphorous content were not obtainable from metal fully blown to approximately 1 pct manganese residual. Low phosphorous slags were produced only when more than 3 pct manganese was left in the metal. This represents too great a loss of manganese in the blown metal. A special blowing procedure was therefore developed[2] whereby the metal was blown to a manganese content of around 1 pct and discharged from the converter. The slag retained in the converter carried about 10 pct iron and 1 pct phosphorous. These constituents were then reduced by the next spiegel addition to a low value of 3 pct iron and 0.05 to 0.2 pct phosphorous. At this stage, the slag contains 55 to 60 pct manganese and is a synthetic high grade manganese ore. The slag was

Table I. Composition of Slags Produced in 1-Ton Converter

Type of Slag	Composition, Pct					Magnetic Material Removed Prior to Analysis, Pct
	Mn	Fe	P	SiO_2	Al_2O_3	
Fluid High Silica Slag:						
Furnace Sample	54-58	1.5	0.04	18-21	2	0.2
Crushed Product		1.5	0.07	18-21		0
Viscous Low Silica Slags:						
Good Operating Conditions						
Furnace Sample	60-64	3.5	0.09-0.16	9-14	1-3	10-18
Magnetic Concentrate at $-\frac{1}{4}$ in.		3-6	0.20	9-14		13
Poor Operating Conditions						
Furnace Sample	59-65	3-6	0.1 -0.17	7-13	1-3	13-25
Magnetic Concentrate at $-\frac{1}{8}$ in.		5-8	0.25-0.40	6-11		

then discharged and the metal retained in the converter for a further blow to low manganese content, after which the cycle was continued as described.

A major purpose of the tests with the 1-ton converter was to establish a procedure for carrying out this cyclic converter operation of removing metal and slag at different times. The slags produced during the period in which the metal is blown to a low manganese content are always low in silica and very viscous so that when the converter is tilted the metal will pour readily without the removal of appreciable slag. The next batch of spiegel added to the converter increases the silica content of the slag and, therefore, causes the viscous slags to become more fluid, the degree of fluidity depending on the silicon content of the metal added. The method employed for removing the slag depends on the slag fluidity. Slags containing over 20 pct silica, which are very fluid, can be poured from the converter without loss of much metal by tilting it carefully. Slags with 15 to 20 pct silica appear fluid, but on tilting do not flow readily from the furnace with the result that considerable metal pours simultaneously. The best procedure for such slags is to pour both slag and metal into a ladle of proper size so that the metal will fill the ladle up to the slag spout. The slag then overflows from the ladle into a slag thimble. The very viscous slags containing around 10 pct silica are the most readily handled. The metal is poured from under the slag after which the converter is inverted to discharge a dry appearing slag.

Table I lists typical compositions of fluid high silica slags and viscous low silica slags. Samples were taken molten from the converter with a spoon and also from the crushed product. Each sample was concentrated magnetically before analysis to remove entrapped metal globules.

The fluid slags contained scarcely any entrapped metal. Both samplings indicated equivalent compositions except for an occasional slightly higher phosphorous level in the crushed slag.

On the other hand, all of the low silica viscous slags carried considerable entrapped metal containing approximately 4 pct phosphorous To obtain a low phosphorous slag, this entrapped metal must be removed by magnetic concentration of the crushed product. Spoon samples indicated that the slag phosphorous content was low—0.09 to 0.17 pct. The magnetic material can be removed quite effectively from many viscous slags by crushing to $-\frac{1}{4}$ in. before magnetic concentration, thus obtaining a product with 0.2 pct or less phosphorous as shown in the table. However, some of the low silica converter slags produced under poor operating conditions have a phosphorous content in excess of 0.4 pct when so treated. Finer grinding followed by magnetic concentration lowers the phosphorous content, but it may be in the range 0.25 to 0.40 pct as shown in the table. While such slags do not meet the standard specifications for phosphorous, a mixture of such slag with the low phosphorous, high silica slag would be acceptable for ferromanganese production.

The distribution of manganese in products of the converter was approximately as follows: In slag, 82 pct; in dry cleaner, 1.6 pct; in wet washer discharge, 1.3 pct; loss up stack, 2.5 pct; in hood scale, 1.0 pct; in discharged metal, 6 pct; and unaccounted for, 5.4 pct. The wet washer discharge would be a usable product after agglomeration. The dry cleaner product and hood scale could be returned to the converter. Electrostatic precipitators or bag filters could recover most of the manganese lost in the flue gases. The manganese in the blown metal, which is about 6 pct of the manganese in the spiegel charged to the converter, represents the only major irrecoverable loss in the process. Consequently, manganese recoveries of 90 pct might be achieved in continuous commercial operations.

The pilot plant tests indicate that about half of the manganese requirements of the country could be supplied from open hearth slag by the process described. Unlike ore deposits which become depleted, this source of manganese will continue as long as the iron ores used contain near the present average of 0.75 pct manganese. The process does not have any unusual technical difficulties and employs standard equipment which has been developed for large-scale operations. Consequently, a large plant could be constructed or existing facilities converted to manganese recovery by this process. Although the investigation was started to provide an emergency source of manganese, the method may provide a domestic source of manganese competitive with foreign ores, especially if the price of such ore continues to rise. To accomplish this objective, the by-products—iron, phosphate slag, and gas would have to be used to fullest advantage so the credits would defray a large part of the cost of operation.

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Use of physically hot iron from the blast furnace is said to result in less variation in chemical analysis, sharper and quicker reaction in the open hearth, and heats of better quality.

Physically Hot Iron Preferred For Open Hearths

by Donald M. Morrison

IT has become commonplace to advocate operating blast furnaces to make slag as lean as possible, allowable sulphur in the iron usually the limiting factor. There has been much interest in external desulphurization partly because still leaner slags may thus be feasible.

This article deals mainly with production of hot metal for direct use in open hearth furnaces and has two objectives. First, to reemphasize the desirability of making the best possible slag, not necessarily the leanest. Second, to restate the open hearth viewpoint with the hope that this will assist in bringing back a wider exchange of ideas and information between blast furnace and open hearth people, as existed about 1940.

Open hearth operators seem to prefer physically hot iron. A careful review of published opinion has failed to locate any disagreement. This kind of iron, other factors being the same, is of necessity produced by furnaces which make slags somewhat more basic than those of maximum acidity where hot metal sulphur is the limiting factor.

Reinartz[1] says "Physically hot molten iron is a prerequisite for quality steel production" and in a second reference[2] states that a coke rate 100 lb higher may produce iron which enables the open hearth operator to make steel at a net saving for the plant as a whole. Ramsey[3] asks for a better and more uniform grade of hot metal; iron analyzing within a reasonably close chemical range, especially silicon, and physically hot. Berner[4] says that "We prefer 0.95 to 1.05 pct silicon in our hot metal for several reasons. --- While we would be very glad to take iron with the silicon range 15 points lower, experience has been that iron made to that range is generally physically cold. It is also apt to occasionally fall too far below the 0.75 pct minimum set ---." Urquhart[5] prefers 0.90 to 1.20 pct silicon and explains that most open hearth operators "--- desire high-temperature iron for various reasons --- less trouble with metal mixer, less skulling in ladles, sharper working heats, etc." Brewster[6] states that "--- the open hearth reaction is much sharper and quicker when the temperature of the hot-metal charge is on the high side." Nelson[7] pre-

Table I. Effect of Hot-Metal Temperature on Steel Quality

No. Heats	40	15	21	30	36
Avg. Casting Temperature °F	2737	2713	2679	2660	2645
Silicon, Pct	1.10	1.11	0.95	1.02	1.00
Sulphur, Pct	0.028	0.028	0.040	0.030	0.037
No. Poor Heats	0	0	0	1	5

DONALD M. MORRISON is a Metallurgical Engineer with A. J. Boynton & Co., Chicago. This paper will be presented at the Blast Furnace, Coke Oven, and Raw Materials Conference, Buffalo, Apr. 20 to 22, 1953.

sents some data, shown in Table I, which apparently show fewer poor heats with hotter iron.

Lambing[9] states that "*cold-bottom* pig iron is undesirable because it goes into the furnace dead, causing excessive foaming and little furnace action. This type of iron is reported also to cause erratic melts, higher sulphur contents, a retarding of rise in bath temperature, and a production of lower quality steel. --- The industry was canvassed--. The most important item suggested by all is to determine how to consistently and economically produce a physically hot iron with low silicon and low sulphur and keep the manganese within desired limits."

Slags of Various Basicities

Prevailing blast furnace opinion is that to produce the physically hot metal which the open hearth prefers means 1—prohibitively higher costs, 2—less tonnage produced, and 3—more irregular operation. Considerable published information seems to show that these three objections are not always true.

A higher cost of iron from a furnace making limier slag would result largely from an increased coke rate. Bond, in discussing Hogberg's[9] paper says "Contrary to opinion, our best results [at Lone Star] are obtained when operating on a limey slag, with iron sulphur in the 0.020's and 0.030's."

Kennedy and Thornton[10] present data which show an optimum slag condition with bases-to-acids ratio of 1.14 where operating results while making Bessemer iron were superior to those obtained with slags with ratios of 1.09, 1.16, and 1.22. Table II compares the practice when using 1.14 and 1.09 ratios, the flux being 65 pct limestone—35 pct dolomite, and 100 pct limestone, respectively.

Table II. Comparison of 1.09 with 1.14 Bases/Acids Ratio

No. Casts	45	70
Avg. Silicon in Iron, Pct	1.60	1.53
Avg. Sulphur in Iron, Pct	0.023	0.018
Avg. Sulphur in Coke, Pct	1.01	1.05
Bases-to-Acids Ratio	1.09	1.14
Iron per Day, Net Tons	838	855
Coke, Lb per Net Ton Iron	1846	1822
Avg. Iron Temperature, °F	2685	2706

Wheldon and Hanna[11] furnish the results of a test, which when analyzed, show a slight improvement in coke rate, and about three pct less tonnage produced, when making high sulphur iron. Table III compares the results.

Unpublished information from the Kaiser Steel Co. Fontana plant shows the superiority of practice averaging 1.09 bases-to-acids ratio when compared with a ratio of 1.04. The information, for ten months' operation of No. 1 furnace during 1951, is shown in Table IV. Two months have been dropped from the tabulation since blast heats were abnormally low because of stove repairs.

Few blast furnace operators are on record regarding the advisability of avoiding excessively lean slags. There is no argument as to the reasons why excessive basicity is unwise. Haven[12] points out that "Other operating practices which affect lining life [adversely] are the use of excessively basic or acid slags ---." Boynton[13] mentions some difficulties involved in operating with lean slags and high blast heats and says "It is seldom that all of these requirements are fulfilled. Consequently, in many cases where the use of acid slags and high heats has been

Table III. Results of Test, High vs Lower Sulphur Iron

Period	Sept. 22-Oct. 16	Oct. 18-Nov. 19
Avg. Silicon, Pct	0.85	0.91
Avg. Sulphur, Pct	0.036	0.050
Avg. Blast Heat, °F	942	888
Coke, Lb per Net Ton Iron	1792	1781
Iron per Day, Net Tons	677	657

attempted, no consistent increase in burden was possible, and the results have been chiefly noticeable in iron alternately too hot and too cold, and in the presence of scouring slags, together with an undue wearing of the lining ---."

It is believed that the data and opinions presented are significant. It is apparent that at a number of plants, the best practice is not always the one with the leanest slag.

Observations

These are based mostly on Chicago district practice during the years 1939 to 1947. It is impractical and outside the scope of this paper to describe slags specifically. The general terms lean, leaner, limey and limier are used. The range of Bases/Acids ratios encountered, using monthly averages, was about 0.89 to 0.98 for basic iron. A slag considered neither lean nor limey would make a black glassy chill sample with a smooth fracture. A brown, splintery, glassy slag sample would be considered lean and a smooth grey-white stoney chill would be limey.

The effects caused by variations in manganese, alumina and magnesia content are not discussed since there were no important changes in slag practice during this period of personal observations. The slags contained about 14 pct alumina and 3 pct magnesia.

Tonnage and coke rate: No outstanding results were obtained from lean-slag operations. A number of coke-rate and tonnage records were set using somewhat limier slags, and those having a black glassy chill sample with smooth fracture were considered ideal.

Quality control: Furnaces operated with lean-slag practice often showed the results mentioned by Boynton[13] with iron alternately too hot or too cold, as indicated by chemical analysis. *Swings* from hot to cold took place more rapidly on the leaner furnaces, which on occasion seemed to go *almost out* for no good reason.

It is felt that a physically hotter and somewhat limier furnace is less likely to be upset because of the stabilizing effect of a hotter reservoir of molten metal (eventually the salamander) below the level of the tapping hole, and because of the stabilizing influence of a moderate amount of a limey deposit on the bosh. Hogberg[9] discusses the adverse effect of such deposits quantitatively, and needless to say, if such deposits become too large, the furnace is too limey and trouble, more or less serious, will probably occur. It is believed that this deposit, if not too large, helps make furnace operation more uni-

Table IV. Comparison of 1.04 with 1.09 Bases/Acids Ratio

Range, Bases-to-Acids Ratio	1.02-1.05	1.06-1.10
Avg., Bases-to-Acids Ratio	1.04	1.09
Avg. Coke Rate, Lb per Net Ton Iron	1410	1356
Avg. Iron per Day, Net Tons	1263	1324
Blast Heat, °F	1210	1263
Flue Dust, Lb per Net Ton Iron	51	57
Tuyeres Burned per Month	7	8

form by 1—preserving the lines of the bosh substantially as built with no projecting bosh plates or enlarging of area, and 2—shrinking or growing in thickness as the lime requirement of the furnace changes within small limits thus making the slag chemistry more uniform.

It is known that rather small changes in slag composition sometimes cause major changes in furnace operation. Personal experience was gained at a time when if the limestone in the burden on a furnace varied within ± 4 or 5 pct over a period of weeks, the process was considered to be in good control.

Stock movement: The lean-slag practice sometimes caused irregular stock movement and blowing through. This was shown by the stock line and top pressure recorders. These symptoms are usually associated with a furnace which is too limey but the iron analysis, the appearance of the slag chill samples, and the presence of considerable burning gas around the bosh all indicated a lean condition which could be corrected by adding stone to the burden. With an apparently ideal slag, stock movement was regular.

Hot spots on shells: The apparent irregular stock movement noted above apparently persisted and grew worse on a number of the furnaces operated with leaner slags. The slag around the cinder notch of the affected furnace would grow increasingly hot and limey, and the opposite side would become cold and lean. Usually a serious hot spot developed above the mantle and over the hot, limey sector. There was far less of this trouble on the furnaces making ideal black glassy slag. This comment excludes hot spots caused by carbon deposition, scabs, or other causes.

Breakouts: Furnaces operated consistently with the leaner slags seemed to be much more likely to suffer breakouts through the hearth cooling staves. None occurred with the limier slag practice during the years of practical experience and there was no mention of previous breakout history.

To offer another opinion; apparently physically cold iron from lean-slag practice, as shown by an almost total lack of graphite precipitating out of the iron during the cast, is not able to maintain a protective carbon coating for ceramic hearth refractories.

Tapping-hole practice: The bad effects of excessively limey slag on tapping-hole practice, rough casts, coke messes and short holes, are well-known. The consistently lean furnaces were more likely to stop casting, entirely or almost so, at unpredictable times. On occasion, casts were finished after up to two hours' delay, following the work involved in burning hundreds of feet of *oxygen pipe* and many poking bars. This condition was seldom seen when operating with somewhat limier slags.

The logical explanation of this irregularity is that because of the physically cold hearth, mushy iron or stringy viscous slag is far more likely to appear at the tapping hole of a lean-slag furnace. It is apparent that poking bars and oxygen pipe are a slow remedy, once the condition appears.

Summary: No personal experience was gained while working on any furnace which did outstanding work on lean slags. Some of the furnaces operating on limier slags performed very creditably. When making basic iron, the slag previously described, which made a smooth, black, glassy chill sample, was ideal. Leaner slags, which consistently made a brown, glassy splintery chill sample, invariably led to irregular operation with a product higher in silicon and sulphur.

Conclusions

Open hearth operators prefer physically hot metal from the blast furnace. The following reasons for this choice are commonly given:

1—Less variation in chemical analysis, especially silicon.

2—A sharper and quicker reaction in the open hearth furnace.

3—Heats are of better quality.

Most blast furnace thinking favors slag practice as lean as possible, iron sulphur being the limiting factor, which means hot metal tending to be physically cold. Scattered opinion and data show evidence of some improved results from operations where slags have a high bases-to-acids ratio, 1.14.

Personal observations force the conclusion that a slag neither excessively lean nor limey is best. It is opined the major benefits from such practice are:

1—Physically hotter iron of more uniform quality.

2—Fewer hot spots on furnace stacks.

3—Fewer breakouts through hearth cooling staves.

Open hearth operators' preference, evidence of what has been done in several plants, and personal observations indicate that the optimum slag condition for the time, place, and materials available should be the goal; not the leanest possible slag which will produce iron with acceptable sulphur content.

Acknowledgment

The teaching and help of fellow-workers over the years, and the recent advice and criticism by A. J. Boynton, H. E. Kaufman and L. V. Dillon are appreciated.

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Effect of Various Elements on Hot-Working Characteristics And Physical Properties of Fe-C Alloys

by C. Travis Anderson, Robert W. Kimball, and Francis R. Cattoir

ONE of the principal impurities in all steels is sulphur. Sulphur-bearing, manganese-free steels exhibit hot shortness. Manganese is added to steel to improve the hot-working properties. If no sulphur were present in steel, it is probable that hot shortness would be nonexistent.

This paper is the first of a series to be issued by this Laboratory reporting the measurements of hot forgeability tests and the physical properties of Fe-C alloys to which additions of various alloying elements have been made. The present paper describes the results obtained by the addition of varying amounts of sulphur to Fe-C alloys.

To obtain control over residual elements in the various charges melted in the arc furnace, it was considered advantageous to use sponge iron from one source as the melting stock rather than scrap metal having an unknown history. Small amounts of unwanted alloying elements might be introduced into the charge when scrap was used, thereby influencing the results of the various heats.

A sponge iron having a high silica-lime ratio was used. Ore from Sunrise, Wyo., had been reduced to sponge iron and briquetted at the Bureau of Mines sponge-iron plant at Laramie, Wyo. The briquettes were 5 in. in diam and 2 to 3 in. in thickness, and weighed about 10 lb each. The chemical analysis of the sponge iron is as follows: C, 0.67 pct; Mn, 0.10; SiO_2, 4.75; CaO, 1.4; P, 0.044; S, 0.72; MgO, 0.4; Al_2O_3, 1.1; total Fe, 87.5; Fe metallic, 79.2; and reduction, 90.5 pct.

Where a reducing agent was required, crushed graphite electrodes usually were used. The charcoal available contained 0.20 pct S. An analysis of the available coke showed it to contain 0.70 pct S. Where high sulphur heats were required, elemental sulphur additions were made to the ladle.

Limestone of good quality was obtained locally and had the following analysis: CaO, 53.7 pct; MgO, 0.8; ignition loss, 42.4; R_2O_3, 0.2; SiO_2, 3.0; and P_2O_5, 0.014.

Melting Procedure

Sponge iron was melted to produce metal stock for the experimental alloys in a silica-lined, three-phase, direct-arc, size ST, Moore Rapid Lectromelt furnace with a 500 kva rating. Fig. 1 shows this furnace installation. About 25 tons of sponge iron was melted in 75 heats, averaging 927 lb of sponge iron to the heat. An addition of carbon was required to complete the reduction of a portion of the iron oxide remaining in the sponge to prevent high losses of iron oxide in the slag and a low carbon content in the resulting metal. As reducing agents in preparing the melting stock, charcoal, coke, and a carbon product resulting from the thermal decomposition of natural gas were used. The quantity varied from 20 to 60 lb per furnace charge, with an average of 38 lb. An average analysis of the metal obtained gave 0.52 pct C, about 0.01 pct Mn, 0.070 pct P, and 0.092 pct S. The average yield of metal was 647 lb with 241 lb of slag, the sponge-iron recovery being 70 pct. The metal obtained in melting the sponge iron was cast into pigs weighing about 20 lb each to facilitate recharging into the furnace for further refining. The pouring of the pigs is shown in Fig. 2. The average power consumption for the production of the 24 tons of metal obtained was 1704 kw-hr per ton.

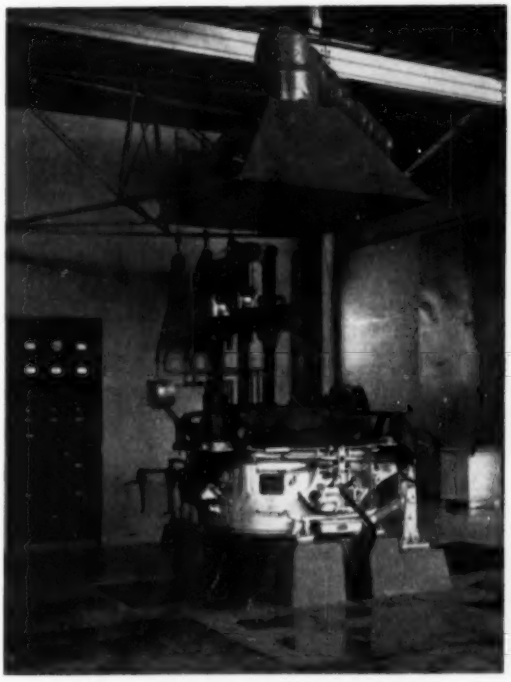

Fig. 1—Electric arc furnace installation.

C. T. ANDERSON, Member AIME, is Chief, R. W. KIMBALL is Technologist, and F. R. CATTOIR is Chemist, Ferro-Alloy Research Branch, Region III, U. S. Bureau of Mines, Redding, Calif.

Discussion on this paper, TP 3448C, may be sent, 2 copies, to AIME by June 1, 1953. Manuscript, June 30, 1952. New York Meeting, February 1952.

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The Transactions papers appearing in the Journal of Metals during 1953 will subsequently appear in AIME Transactions Volume 197, and may be permanently referenced to that volume.

Fig. 2—Pouring of pigs from lip pouring ladle.

No slag-making or alloy additions were made to these heats, as the metal was subsequently remelted to remove manganese, silicon, phosphorus, and sulphur in a basic-lined furnace under a high-lime oxidizing slag.

A series of 22 heats was made on the melting stock in the basic-lined furnace under the oxidizing slag. After the metal had melted, the oxidizing slag was removed and a reducing slag formed for additional sulphur removal. Considerable sulphur is removed from high-sulphur metal under an oxidizing slag, but the reducing slag removed it much more rapidly.

The results obtained in these 22 heats on the removal of phosphorus are clearly observed in Table I. Temperature control in the furnace had considerable influence on sulphur and phosphorus. High temperatures were necessary to obtain the reductions desired. Where the melt-down carbon is very low, removal of phosphorus is excellent, but where melt-down carbon is high, phosphorus removal is very poor, indicating the oxidizing conditions necessary for good phosphorus removal. This table also shows the phosphorus pick-up in the metal during the reducing-slag treatment. Even though great care was taken in removing the oxidizing slag as completely as possible, some reversion of phosphorus took place during the reducing-slag treatment. After every other possibility was eliminated, it was concluded that the pick-up was obtained from the fireclay roof. It may be noted that a considerably larger pick-up than normal occurred in heat 26B. The reducing slag in this heat was held on the metal much longer than normal. The average increase in phosphorus during the reducing-slag treatment was 0.017 pct. During the latter part of the experimental work a virtually phosphorus-free basic roof was installed, and this phosphorus pick-up was eliminated.

The average sulphur removed by the oxidizing slag was 0.017 pct, whereas 0.067 pct was removed by the reducing slag.

These 22 heats were remelted under an oxidizing slag to remove further manganese, silicon, phosphorus, and sulphur. The results of the remelting are shown in Table II.

Heats 44, 47, and 48 did not receive further treatment. Heat 44 was tapped from the furnace and a 200-lb ingot with a hot top poured. The metal was killed by the addition of aluminum pellets. Carbon was added to the molten-metal bath of heat 47 to produce a material containing 3.72 pct C. Pigs from heat 47 were added to heat 48 to raise the carbon content to 0.20 pct. No reducing slag was used on these three heats. Table III shows the results of remelting the heats shown in Table II to produce the alloys used in the tests described in this paper. Heat 17 was remelted to produce heat 18, which in turn was remelted to produce heat 19. Heat 46 had no aluminum added for deoxidation. Heat 64 was remelted for phosphorus removal to produce heat 65 having a sulphur content of 0.002 pct.

Fabrication of Samples

One ingot with a hot top was poured from each final heat shown in Table III. The ingots weighed 200 to 220 lb and were 6x6x24 in. in length including

Table I. Removal of Phosphorus and Sulphur from Metal

		Phosphorus, Pct					Sulphur, Pct				
Heat No.	Melt-Down Carbon	At Start of Heat	Melt Down	Removed	At Tap	Pick-Up from Melt Down	At Start of Heat	Melt Down	Removed	At Tap	Removed from Melt Down
1	0.024	0.072	0.017	0.055	0.040	0.023	0.099	0.090	0.009	0.033	0.057
2	0.034	0.071	0.013	0.058	0.029	0.016	0.097	0.094	0.003	0.014	0.080
3	0.030	0.073	0.006	0.067	0.027	0.021	0.098	0.076	0.022	0.011	0.065
4	0.024	0.072	0.007	0.065	0.020	0.013	0.097	0.073	0.024	0.015	0.058
5	0.036	0.071	0.003	0.068	0.022	0.019	0.104	0.065	0.039	0.018	0.047
6	0.032	0.070	0.004	0.066	0.020	0.016	0.096	0.071	0.025	0.011	0.060
7	0.050	0.070	0.004	0.066	0.027	0.023	0.097	0.070	0.027	0.010	0.060
8	0.088	0.073	0.006	0.067	0.027	0.021	0.095	0.066	0.029	0.010	0.056
20	0.078	0.068	0.022	0.046	0.030	0.008	0.097	0.072	0.025	0.010	0.062
21	0.108	0.069	0.024	0.045	0.043	0.019	0.093	0.076	0.027	0.022	0.054
22	0.046	0.072	0.008	0.064	0.031	0.023	0.100	0.072	0.028	0.008	0.064
23	0.043	0.071	0.007	0.064	0.024	0.017	0.093	0.076	0.017	0.010	0.066
24	0.066	0.073	0.011	0.062	0.036	0.025	0.095	0.087	0.008	0.007	0.080
25	0.081	0.074	0.028	0.046	0.038	0.010	0.090	0.085	0.005	0.010	0.075
26	0.058	0.070	0.009	0.061	0.044*	0.035	0.092	0.080	0.012	0.007	0.073
27	0.031	0.069	0.003	0.066	0.027	0.024	0.098	0.079	0.019	0.009	0.070
28	0.038	0.073	0.014	0.059	0.030	0.016	0.098	0.081	0.017	0.005	0.076
29	0.162	0.065	0.045	0.020	0.055	0.011	0.089	0.089	0.000	0.005	0.084
30	0.102	0.071	0.038	0.033	0.052	0.014	0.094	0.093	0.001	0.011	0.082
31	0.031	0.071	0.009	0.062	0.027	0.018	0.096	0.081	0.015	0.005	0.076
32	0.036	0.073	0.007	0.066	0.030	0.023	0.098	0.077	0.021	0.006	0.071
33	0.150	0.069	0.042	0.027	0.052	0.010	0.093	0.089	0.004	0.010	0.070

* Long heat.

Table II. Results of Remelting Heats in Table I

Heat No.	Remelt of Heat No.	Melt-Down Carbon	Phosphorus, Pct					Sulphur, Pct			
			At Start	Melt Down	Removed	At Tap	Pick Up	At Start	Melt Down	Removed	At Tap
9	1	0.067	0.040	0.004	0.036	0.013	0.009	0.033	0.029	0.004	0.007
10	2	0.063	0.029	0.002	0.027	0.015	0.013	0.014	0.012	0.002	0.003
11	3	0.046	0.027	0.004	0.023	0.017	0.013	0.011	0.012	0.001	0.004
12	4	0.071	0.020	0.002	0.018	0.012	0.010	0.015	0.014	0.001*	0.004
13	5	0.078	0.022	0.004	0.018	0.012	0.008	0.018	0.015	0.003	0.003
14	6	0.057	0.020	0.003	0.017	0.009	0.006	0.011	0.010	0.001	0.005
15	7	0.050	0.027	0.005	0.022	0.017	0.012	0.010	0.012	0.002*	0.004
16	8	0.078	0.027	0.008	0.019	0.016	0.008	0.010	0.012	0.002*	0.004
34	26	0.032	0.044	0.005	0.039	0.018	0.013	0.007	0.015	0.008*	0.004
35	21	0.027	0.043	<0.001	0.043	0.020	0.019	0.022	0.025	0.003*	0.003
36	29	0.037	0.055	—	—	0.020	—	0.005	0.009	0.004*	0.003
37	33	0.088	0.052	0.018	0.034	0.025	0.007	0.010	0.026	0.016*	0.005
38	30	0.039	0.052	<0.001	0.051	0.015	0.014	0.011	0.012	0.001*	0.003
39	32	0.027	0.030	0.002	0.028	0.019	0.017	0.006	0.016	0.010*	0.004
40	28	0.043	0.030	<0.001	0.029	0.017	0.016	0.003	0.007	0.002*	0.003
41	22	0.026	0.031	<0.001	0.030	0.020	0.019	0.008	0.009	0.001*	0.005
42	31	0.031	0.027	<0.001	0.026	0.009	0.008	0.005	0.006	0.001*	0.002
43	23	0.024	0.024	<0.001	0.023	0.010	0.009	0.010	0.007	0.003	0.004
44†	27	0.027	0.027	<0.001	0.026	<0.001	0.000	0.009	0.007	0.002	0.005
45†	24	0.025	0.036	<0.001	0.035	<0.001	0.000	0.007	0.007	0.000	0.004
47‡	20	0.019	0.030	<0.001	0.029	<0.001	0.000	0.010	0.009	0.001	0.006
48†	25	0.036	0.038	<0.001	0.037	0.002	0.001	0.010	0.007	0.003	0.006

* Increase.
† No reducing slag was used. In heat 48 final carbon was obtained by addition of pig iron.
‡ In heat 47 final carbon was 3.72 pct.

the hot top. These hot tops were cropped by sawing. The cropped portion of the ingot weighed about 50 lb, leaving about 150 lb to be worked into test specimens. The ingots were heated in a butane-gas-fired furnace to about 2300°F and forged under an air hammer to approximately 1-in. rounds. The rods were then cold-swaged in a rotary swager to $\frac{5}{8}$-in. rods, samples being removed at $\frac{3}{4}$-in. diam for tensile and other physical tests. The rods were annealed at intervals during the swaging to relieve the hardening induced by the cold-working operation.

Evaluation of Hot-Working Characteristics

The "hot-twist test" was selected as the most suitable means of conducting the elevated temperature tests in the hot short range. This method has recently been described by Clark and Russ[1] and Ihrig.[2] While not entirely satisfactory, the test yields reproducible results that serve as an indication of the hot-working properties of the metal. The equipment used is rather simple; and, as Clark and Russ pointed out in their studies, the test requires very little time and is a torsion test in which the predominating stresses are in shear.

Fig. 3 shows the equipment used for the test. It consists of a furnace for heating and maintaining the specimen at the desired temperatures. The furnace has upper and lower sections which are hinged to allow easy placement and removal of the bar being twisted, and also to facilitate chucking the test pieces. A 3-hp motor with a reduction gear is attached to a chuck for holding and rotating the specimen. At the opposite end of the chuck end of the furnace the sample is held firmly by a dog, which prevents the specimen from rotating. All results except as otherwise noted were carried out at about 200 rpm and at 50° temperature intervals from 1550° to 2000°F. The temperatures used covered the red short range. By means of an electrical circuit, an automatic counter records the number of turns before failure. Table IV gives the analysis for carbon, manganese, silicon, phosphorus, and sulphur of the rods used in the experiments.

Table V shows the results of the twisting tests obtained on the rods containing varying amounts of sulphur. These results clearly show that, as the sulphur content of the metal decreases, the number of twists to failure increases. Heat 65, having only 0.002 pct S, shows very good hot-working properties. Hot-working properties of materials above 0.010 pct S are uniformly poor. Of two ingots containing 0.017 pct S, only one could be forged to produce rod for testing.

Fig. 4 shows the results of an attempt to forge an ingot from heat 55 containing 0.021 pct S. A few blows by the forging hammer fractured the ingot.

Table III. Results of Remelting Heats in Table II

Heat No.	Melt-Down Carbon	Phosphorus, Pct		Sulphur		
		Melt Down	At Tap	Melt Down, Pct	Added Grams	At Tap, Pct
17	0.059	0.002	0.008	0.007	—	0.003
46*	0.029	<0.001	<0.001	0.004	—	0.004
49	0.025	<0.001	0.002	0.005	—	0.006
50	0.024	<0.001	<0.001	0.007	—	0.007
51	0.043	<0.001	0.002	0.004	—	0.004
52	0.029	<0.001	0.003	0.013	—	0.009
53	0.021	<0.001	0.003	0.010	225	0.032
54	0.042	<0.001	<0.001	0.018	—	0.011
55	0.042	<0.001	0.002	0.008	100	0.021
56	0.031	<0.001	0.001	0.013	50	0.017
57	0.034	<0.001	0.003	0.010	32	0.017
58	0.034	<0.001	0.002	0.010	30	0.015
59	0.028	<0.001	0.002	0.007	25	0.011
60	0.025	<0.001	0.001	0.010	32	0.013
61	0.040	<0.001	0.001	0.010	27	0.014
62	0.034	<0.001	0.001	0.009	25	0.012
63	0.041	<0.001	0.001	0.010	10	0.010
64	0.030	<0.001	0.010	0.005	—	0.002
18†	0.068	0.002	0.007	0.004	—	0.002
65‡	0.048	<0.001	0.004	0.005	—	0.002
19§	0.075	0.002	0.002	0.003	—	0.004

* No reducing slag.
† Remelt of heat 17.
‡ Remelt of heat 64 for phosphorus removal.
§ Remelt of heat 19.

Table IV. Analyses of Ingots

Ingot No.	Analysis, Pct					
	C	Mn	Si	P	S	
65	0.23	0.003	0.115	0.004	0.002	
51	0.21	0.004	0.004	0.002	0.004	
48	0.20	0.003	<0.001	0.002	0.006	
49	0.32	0.003	0.002	0.002	0.006	
50	0.30	0.002	0.003	<0.001	0.007	
52	0.17	0.001	0.001	0.003	0.009	
63	0.26	0.002	0.002	0.001	0.010	
54	0.37	0.002	0.004	0.001	0.011	
59	0.24	0.003	0.005	0.002	0.011	
62	0.29	0.002	0.002	0.001	0.012	
60	0.16	0.003	0.003	0.001	0.013	
61	0.22	0.002	0.003	0.001	0.014	
58	0.23	0.003	0.004	0.002	0.015	
57	0.24	0.003	0.003	0.003	0.017	
56	0.27	0.003	<0.001	0.001	0.017	
55	0.24	0.002	<0.001	0.002	0.021	
53	0.23	0.004	0.004	0.003	0.032	
19	0.061	0.004	0.002	0.002	0.004	2# Al/ton furnace
46	0.019	0.001	0.002	<0.001	0.004	No Al
44	0.024	0.002	<0.001	<0.001	0.005	Al to mold

Table V. Twists to Failure

Ingot No.	Temperature, °F										S, Pct	C, Pct	
	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000			
65	238	215	209	200	227	261	283	305	317	440	0.002	0.23	
51	45	31	27	23	22	20	23	25	29	39	0.004	0.21	
48	14	14	7	5	4	4	5	6	7	10	0.006	0.20	
49	23	18	15	14	12	12	16	18	30	37	0.006	0.32	
50	17	12	11	9	11	10	13	16	27	32	0.007	0.30	
52	9	8	7	7	6	7	8	11	17	22	0.009	0.17	
63	8	7	5	4	3	3	3	3	6	8	0.010	0.26	
54	6	5	4	4	4	4	4	6	7	8	0.011	0.37	
59	8	6	5	4	3	3	4	5	6	8	0.011	0.24	
62	5	5	4	3	2	2	2	3	3	5	0.012	0.29	
60	7	6	4	3	3	3	3	4	5	6	0.013	0.16	
61	6	5	3	3	3	3	3	3	4	5	0.014	0.22	
58	6	4	5	3	2	2	3	3	4	6	0.015	0.23	
57	7	7	5	3	3	2	2	3	3	3	0.017	0.24	
56					Broke on forging						0.017	0.27	
55					Broke on forging						0.021	0.24	
53					Broke on forging						0.032	0.23	
19	30	25	21	20	22	20	18	27	50	55	0.004	0.061	2# Al/ton furnace
46	17	15	10	7	6	6	7	8	11	13	0.004	0.019	No Al
44	16	18	12	8	7	7	7	11	16	45	0.005	0.024	Al to mold

In all samples tested, a minimum number of twists was obtained in the hot-short range from about 1725° to 1825°F.

To determine whether the size of the rod influenced the results obtained in the test, rods of heat 19 were swaged to 5/8, 9/16, 7/16, and 3/8 in. in diam. The number of twists to failure for the rods of the various diameters is shown in Table VI. While these results indicate that the size of rod does not greatly influence the number of twists to failure, it is significant to note that, as the diameter of the rod decreases, the number of twists before failure increases.

To determine whether rate of twisting influenced the results of the twisting tests, a four-speed transmission was connected to the chuck used for twisting the rods. Rates of 47, 96, 180, and 290 rpm were obtained with this arrangement. Rods used were swaged to ⅜-in. diam for this series of tests. The results obtained are shown in Table VII. These results indicate that, as the rate of twisting increases, the number of twists to failure also increases.

Fig. 3—Equipment used for hot-twist testing.

Fig. 4—Cracking of ingot due to hot shortness.

Physical Testing

During the working-down schedule of the rods, samples for physical testing and metallographic examination were removed when the rods reached ¾ in. in diam. The specimens were cut to length for heat treating. The samples were heat-treated and measured or examined in the normalized and annealed conditions. The normalized samples were heated to such a temperature that the material was in the austenitic range, held at that temperature for 1 hr, removed from the furnace, and allowed to cool in still air. The annealed samples were given this same treatment but in addition were returned to the furnace after cooling, held for 30 min, the furnace heat turned off, and the specimens allowed to cool in the furnace. Duplicates were prepared on all samples.

Table VI. Results of Twisting Tests on Rods of Various Diameters

Temperature, °F	Number of Twists to Failure				
	⅝ In.	7/16 In.	⅜ In.	9/16 In.	5/8 In.
1550	53	48	40	31	30
1600	52	52	37	29	25
1650	48	49	26	28	21
1700	37	30	25	27	20
1750	30	23	23	25	24
1800	28	22	24	18	21
1850	29	27	26	23	18
1900	35	34	33	30	27
1950	67	46	43	31	50
2000	71	48	54	53	55

Table VII. Results of Twists on ⅜-In. Rods in Which Rate of Twisting is Varied

Temperature, °F	Number of Twists to Failure			
	47 rpm	96 rpm	180 rpm	290 rpm
1550	62	65	85	94
1600	46	58	74	76
1650	37	45	50	65
1700	27	31	41	50
1750	15	26	32	42
1800	15	21	28	33
1850	12	16	24	29
1900	12	15	24	34
1950	15	19	26	41
2000	19	28	42	56

Impact specimens were standard Charpy keyhole notch-type, with a breaking section of 0.197x0.394 in. Specimens were broken in a Tinius Olsen impact testing machine of 264 ft-lb capacity with a striking velocity of 16.5 ft per sec.

Rockwell-hardness measurements were made on all samples.

Table VIII. Charpy Impact Values and Rockwell B Hardness of Normalized and Annealed Samples

Alloy No.	Charpy Impact, Ft-Lb		Hardness, Rockwell B	
	Normalized	Annealed	Normalized	Annealed
65	44	33	60	45
51	46	27	60	51
48	50	27	58	49
49	32	20	65	59
50	29	13	65	56
52	44	10	61	55
63	41	30	55	43
54	26	20	71	56
59	43	29	53	42
62	40	29	58	48
60	43	28	60	41
61	50	31	60	42
58	48	35	54	36
57	48	30	59	40
19	65	59	44	42
46	45	18	55	48
44	56	24	56	46

The Charpy impact values and the Rockwell B hardness of the samples are given in Table VIII.

Tensile specimens were tested by standard methods, using a threaded 0.505-in. diam test bar in a Baldwin-Southwark testing machine. The yield point was determined by the drop of the beam. The proportional limit and yield strength values were determined from stress-strain diagrams drawn by a Templin recorder.

The mechanical properties of the samples in the annealed condition are given in Table IX, while the results obtained on the normalized specimens are given in Table X. From the results of the various physical properties of the Fe-C-S alloys, it appears that the carbon content exerts the principal influence on these properties. All samples were examined under the metallographic microscope. The annealed samples in all cases contained larger grains and more, coarse lamellar pearlite than the normalized specimens. Fig. 5 shows a micrograph of Heat 50 in the normalized condition, while Fig. 6 shows the same alloy in the annealed state.

Table IX. Mechanical Properties of Annealed Samples

No. Heat	Thousands of Pounds per Square Inch				Pct Elongation in 2 In.	Red Area, Pct
	Proportional Limit	Yield Point	Yield Strength, 0.1 Pct Off	Ultimate Tensile Strength		
65	23.0	32.0	28.0	54.0	34.5	62.4
51	15.4	22.0	23.0	52.0	36.5	66.5
48	16.7	22.0	23.0	50.1	39.5	66.0
49	16.9	25.0	25.0	57.0	32.8	57.0
50	15.0	23.0	23.0	57.1	34.0	55.0
52	34.0	37.5	37.1	51.0	39.0	68.2
63	16.9	24.2	24.1	54.6	35.5	62.9
54	20.4	28.5	28.5	60.4	32.5	56.2
59	16.7	20.9	23.9	54.0	33.0	55.0
62	13.8	24.8	24.8	57.0	33.0	61.0
60	13.3	25.0	24.0	53.6	35.0	63.4
61	15.6	22.4	23.1	52.5	38.0	65.0
58	22.0	28.0	28.0	54.0	36.5	63.9
57	14.8	18.7	18.9	51.5	38.8	64.2
19	30.3	38.8	32.3	44.4	47.2	76.4
46	24.8	26.1	24.1	45.6	35.5	62.4
44	27.2	34.6	32.6	45.2	43.2	79.2

Table X. Mechanical Properties of Normalized Samples

Heat No.	Thousands of Pounds per Square Inch				Pct Elongation in 2 In.	Red Area, Pct
	Proportional Limit	Yield Point	Yield Strength, 0.1 Pct Off	Ultimate Tensile Strength		
65	36.3	42.1	39.3	62.4	35.8	63.4
51	28.4	40.2	35.3	57.9	38.8	65.7
48	32.4	37.9	35.5	56.1	40.5	66.7
49	36.7	45.8	45.6	66.4	33.5	56.0
50	32.5	45.8	41.0	66.4	34.5	71.0
52	29.7	45.8	45.0	59.0	36.0	68.5
63	39.7	50.7	43.8	63.8	31.5	48.4
54	33.0	45.4	40.9	69.7	29.8	54.5
59	40.8	47.4	47.0	62.7	36.5	60.6
62	38.1	47.9	41.2	64.3	33.5	59.9
60	32.8	47.9	41.4	58.8	38.2	66.2
61	31.0	43.4	37.5	60.0	37.2	65.7
58	45.1	47.3	46.1	60.6	37.0	65.6
57	35.7	44.6	41.8	60.5	38.8	65.2
19	38.4	40.5	34.8	47.9	45.0	76.3
46	31.2	35.3	32.4	50.9	34.1	59.5
44	35.9	40.4	38.3	50.4	41.2	77.0

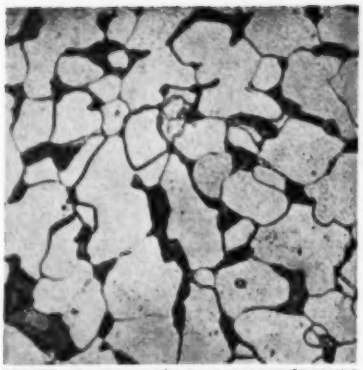

Fig. 5—Typical normalized specimen of Fe-C-S alloy. X700. Area reduced approximately 50 pct for reproduction.

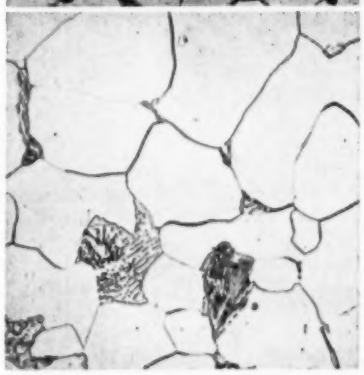

Fig. 6—Typical annealed specimen of Fe-C-S alloy. X700. Area reduced approximately 50 pct for reproduction.

Summary

A series of Fe-C alloys has been prepared at the Redding, Calif., Station of the Federal Bureau of Mines in which the manganese is 0.004 pct or less with low phosphorus and silicon contents but with varying percentages of sulphur. The experimental alloys have been hot-forged and swaged to rods. Hot-twisting tests have been conducted on ⅝-in. rods. The physical properties of the alloys have been determined. Manganese-free Fe-C alloys with more than 0.017 pct S could not be hot-forged. Alloys with more than 0.010 pct S possess very poor hot-working properties. As the sulphur content of the alloys decreases below 0.009 pct, the hot-working properties of the alloys improve. Alloys containing 0.002 pct S exhibit excellent hot-working properties.

Acknowledgments

Acknowledgment is made to John L. Morning, Dean R. Myers, Edward Knakal, and A. G. Pike, former employees, who assisted in the work; to R. G. Dutton, who constructed the hot-twisting equipment and prepared most of the samples for the physical tests; and to E. D. White, who worked on the electrical equipment and conducted a number of hot-twisting experiments.

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Stabilization of the Austenite-Martensite Reaction In a High Chromium Steel

by S. C. Das Gupta and B. S. Lement

No appreciable stabilization of the austenite-martensite reaction occurs in a 15 pct Cr-0.7 pct C steel unless some martensite is initially present. Stabilization is induced by interrupting the subcool below M_s; however, disappearance of the stabilization effect as manifest by burst formation of martensite may occur on continued holding at the final subzero reaction temperature. The higher the temperature of intermediate cycling after the initial subcool, the more permanent is the stabilization effect at the final reaction temperature. Appreciable conditioning of retained austenite occurs on reheating to about 500°C. These phenomena are explainable on the basis of the reaction-path theory.

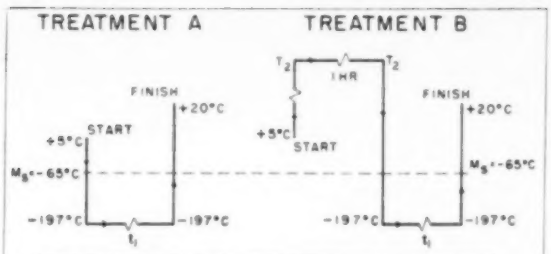
A RECENT investigation[1] carried out by the authors has shown that isothermal transformation of austenite to martensite definitely takes place in a 15 pct Cr-0.7 pct C steel and that appreciable amounts of martensite can form in this fashion. Investigations[2-4] carried out on other steels and iron alloys make it seem probable that isothermal formation of martensite is a phenomenon of fairly general occurrence. The reaction-path theory of Cohen, Machlin, and Paranjpe[5-7] explains isothermal transformation on the basis of thermal activation of strain embryos which generate martensite plates with a velocity approaching that of sound. On the other hand, the nucleation and growth theory of Fisher, Hollomon, and Turnbull[8] regards isothermal transformation as due to growth of athermally formed martensite nuclei. The experimental evidence obtained thus far favors the reaction-path theory in that the martensite reaction seems to be nucleation-controlled rather than growth-controlled.

Stabilization is another phenomenon of importance with respect to the austenite-martensite reaction. According to the reaction-path theory, stabilization is a result of relaxation of strain embryos. It is postulated that strain embryos are present at the austenitizing temperature in the form of dislocations or lattice imperfections in the austenite which vary in the extent to which the lattice is displaced along the strain reaction path leading to martensite. On quenching from the austenitizing temperature, athermal martensite starts to form as soon as the M_s is reached, because the activation energy of the transformation which decreases with decreasing temperature is lowered to below the level of the highest energy strain embryos. Martensite plates are generated during the cooling below M_s from embryos possessing energies above the activation energy corresponding to the temperature at which the cooling is stopped. The distribution of lower energy embryos is changed because of the elastic and plastic strains produced in the remaining austenite as a result of the transformation. This effectively increases the number of strain embryos at all levels of energy below the activation energy and tends to stimulate further martensite formation either isothermally or on subsequent cooling. However, if the temperature at which the cooling is stopped is high enough for relaxation of strain embryos to occur, some degree of stabilization against further transformation may be induced. Whether stabilization will be observed on subsequent cooling will depend on the extent of decrease of activation energy with temperature. If the activation energy decreases sharply with temperature, it is possible that transformation will appear to continue with decrease in temperature in spite of the loss of embryos by relaxation. However, with a more gradual decrease in activation energy, stabilization will be manifest by no further transformation on cooling over a measurable temperature range until the

S. C. DAS GUPTA, formerly Research Associate, Dept. of Metallurgy, Massachusetts Institute of Technology, is now in Calcutta, India, and B. S. LEMENT, Associate Member AIME, is on the Research Staff, Dept. of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

Discussion on this paper, TP 3399E, may be sent, 2 copies, to AIME by Dec. 1, 1953. Manuscript, April 14, 1952. Cleveland Meeting, October 1953.

This paper represents part of a thesis by S. C. Das Gupta submitted in partial fulfillment of requirements for the degree of Doctor of Philosophy in Metallurgy to the University of Notre Dame.



TREATMENT A-RESULTS

TIME OF HOLD AT -197°C t_1	PCT MARTENSITE	
	TOTAL	ISO-THERMAL
0 MIN	14	0
30 MIN	19	5
0 MIN	14	0
30 MIN	19	5

TREATMENT B-RESULTS

TIME OF HOLD AT -197°C t_1	RE-HEATING TEMP T_2	PCT MARTENSITE	
		TOTAL	ISO-THERMAL
0 MIN	250°C	15.5	0
30 MIN	250°C	19	3.5
0 MIN	500°C	20.5	0
30 MIN	500°C	24	3.5

Fig. 1—Effect of reheating prior to cooling below M_s on isothermal transformation at −197°C.

activation energy is decreased below the level of the highest energy embryos that survived relaxation.

Two mechanisms by which relaxation of strain embryos can occur have been proposed by the authors of the reaction-path theory. Relaxation could occur by a recovery process similar to that which occurs prior to recrystallization of cold-worked metals. Another possibility is diffusion of solute atoms such as carbon into strain embryo regions, which results in an increase in the activation energy associated with such regions because of increase in carbon content.

The present investigation was carried out in order to learn more about the characteristics of the austenite-martensite reaction in the 15 pct Cr-0.7 pct C steel. Experiments were designed primarily to study various aspects of stabilization; however, other effects were encountered. These experiments involved prior treatments such as reheating quenched specimens before cooling below M_s, interrupting the cooling below M_s, and cycling from temperatures below M_s to above M_s. The effects of these prior treatments on subsequent athermal and isothermal martensite formation at relatively low subzero temperatures were investigated as further tests of the adequacy of the reaction-path theory.

Experimental Details

The chemical composition of the steel investigated is as follows: C, 0.73 pct; Mn, 0.28; Si, 0.20; S, 0.02; and Cr, 14.84. Specimens approximately 1/16x⅛x¼ in. were sealed in an evacuated quartz tube and then austenitized for 2 hr at 1275°C which resulted in a grain size of ASTM No. 1 to 2 and virtually complete carbide solution. The M_s corresponding to this treatment was found to be −65° ± 5°C. Quenching was carried out in a 10 pct brine solution maintained at 5°C. The quartz tube was broken under the surface of the quenching liquid. The details of the subzero furnace used to attain temperatures down to −150°C have been given previously.[1] Liquid nitrogen was used to attain −197°C. Quantitative determination of the extent of martensite formation was carried out by the method of lineal analysis.[9] The precision measurement is estimated to be ±1 pct martensite.

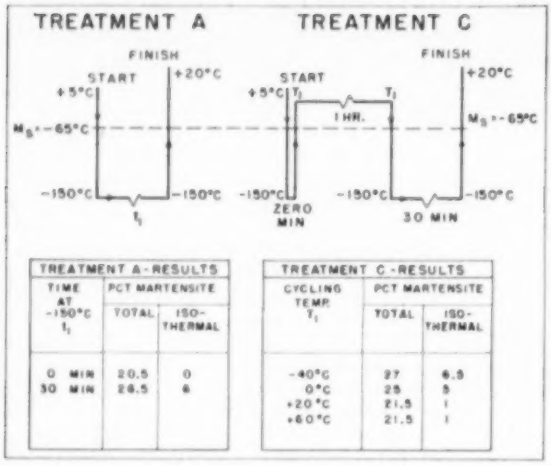
The common starting point for most of the experiments in this investigation was the as-quenched state of specimens quenched from 1275° to 5°C. The specimens were completely austenitic at 5°C. Comparisons were made of isothermal transformation at temperatures of −130° to −197°C with and without prior treatments. The amount of martensite formed as a result of cooling directly to these temperatures was found to be higher than previously reported;[1] however, there was no measurable change in M_s temperature. This could be due to either a slight variation in chemical composition of the bar stock used or some undetermined variable in heat treatment. In order to make the comparisons more reliable, specimens were taken from approximately the same locality in the bar stock. Furthermore, these specimens were austenitized and quenched at the same time before being subjected to the comparative treatments of each experiment. For each experiment, the basis of comparison is treatment *A*, which consisted of subcooling specimens from 5°C to a subzero temperature, holding for a definite length of time, and upquenching to 20°C in water.

Results

Effect of Interrupting Cooling Prior to Subcooling below M_s: The M_s temperature, −65°C, as well as the amounts of martensite formed on cooling to subzero temperatures, was found not to be affected to any appreciable extent by holding specimens quenched from 1275°C even as long as 500 hr at 20°C prior to subzero cooling. These results seemed to be at variance with the findings of Klier and Troiano[10] who concluded that stabilization occurs in this steel as a result of holding above M_s prior to cooling below this temperature. However, there was still the possibility that the stabilization process at 20°C is completed so rapidly that detection is difficult. Further experiments were carried out in order to check this point by duplicating Klier and Troiano's procedure in detail. Specimens 1/32x1/32x1/2 in. were austenitized for 5 hr at 1200°C in purified nitrogen atmosphere. Quenching the specimens directly into refrigerated mercury from 1200°C resulted in an M_s of about −35° ±5°C. However, interrupting the quench from 1200°C for 1 hr at 20°C followed by subcooling also gave the same M_s; thus, no stabilization effect was found. Microscopic examination of specimens austenitized at 1200°C revealed an appreciable amount of undissolved carbides, which means that both the carbon and alloy content of the austenite were lower than for the case of virtually complete solution obtained at 1275°C. This would account for the higher M_s (−35°C as compared to −65°C) resulting from the 1200°C treatment.

Effect of Reheating Prior to Cooling below M_s: In these experiments, specimens were reheated to temperatures as high as 500°C after quenching from 1275°C in brine at 5°C. These specimens were air cooled to room temperature and subsequently subcooled to −197°C. The amounts of martensite formed after holding zero and 30 min at this temperature were then measured. The effect of not reheating (treatment *A*) is compared with that of reheating to 250° and 500°C (treatment *B*) in Fig. 1.

It was found that reheating as high as 500°C does not have any appreciable effect on subsequent isothermal transformation at subzero temperatures. Likewise, reheating to below 250°C does not appreciably affect the amount of athermal martensite formed; however, a 500°C reheat does result in an increase in the amount of transformation formed on subsequent cooling to −197°C. It is possible that the increased athermal transformation is due to some



TREATMENT A-RESULTS		
TIME AT -150°C t_1	PCT MARTENSITE	
	TOTAL	ISO-THERMAL
0 MIN	20.5	0
30 MIN	26.5	6

TREATMENT C-RESULTS		
CYCLING TEMP. T_1	PCT MARTENSITE	
	TOTAL	ISO-THERMAL
-40°C	27	6.5
0°C	25	5
+20°C	21.5	1
+60°C	21.5	1

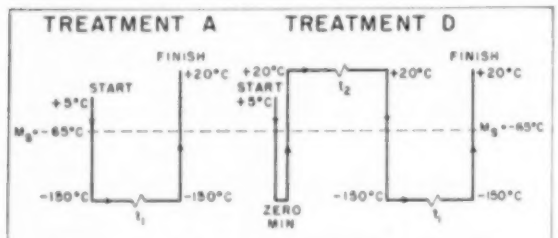
Fig. 2—Effect of cycling temperature on subsequent isothermal transformation at −150°C.

type of conditioning process that occurs in the retained austenite. This conditioning was not found to result in any noticeable increase in the M_s temperature; however, it is possible that a change less than 5°C would not have been detected with the metallographic method employed.

Effect of Cycling from below M_s: The effect of cycling between subzero temperatures below M_s to temperatures as high as 60°C on subsequent isothermal transformation was studied. The results of treatment *C* shown in Fig. 2 for a subzero temperature of −150°C and a 30 min hold indicate that virtually complete stabilization against isothermal transformation is obtained provided that a cycling temperature of 20°C or above is employed. Similar results were obtained for isothermal transformation at −197°C again using a 30 min hold.

This stabilization effect with respect to isothermal transformation was also found to depend on time at the cycling temperature. Using shorter times than 1 hr at 20°C was found to decrease the extent of stabilization at both −150° and −197°C.

Curiously enough, the stabilizing effect which is noticeable for comparatively short holding times at the final reaction temperature is somehow overcome



TREATMENT A-RESULTS		
TIME AT -150°C t_1	PCT MARTENSITE	
	TOTAL	ISO-THERMAL
0 MIN	20.5	0
30 MIN	26.5	6
2 HR	27.5	7
2 HR	27.5	7
8 HR	28	7.5

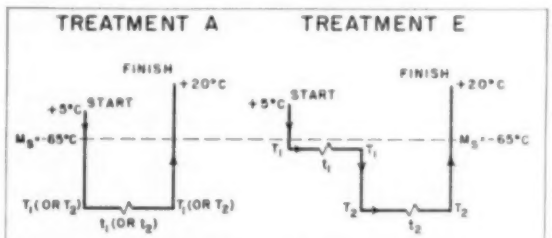
TREATMENT D-RESULTS			
TIME AT +20°C t_2	TIME AT -150°C t_1	PCT MARTENSITE	
		TOTAL	ISO-THERMAL
—	—	—	—
3 MIN	30 MIN	22.5	2
3 MIN	2 HR	28.5	8
15 HR	2 HR	21.5	1
15 HR	8 HR	27.5	7

Fig. 3—Effect of time of hold at −150°C on extent of isothermal transformation following cycling treatment.

if longer times are employed. This phenomenon is shown in Fig. 3 for isothermal transformation at −150°C (treatment *D*). For example, the stabilization effect observed on holding 30 min at −150°C after cycling at 20°C, 3 min hold, appears to be completely overcome on continued holding for a total of 2 hr at −150°C. Similarly, after cycling at 20°C, 13 hr hold, the stabilization effect found on holding 2 hr at 150°C seems to disappear on continued holding for a total of 8 hr at this temperature. Further experiments at both −150° and −197°C established that the stabilizing effect tends to become more permanent the higher the cycling temperature or the longer the time at a given cycling temperature. For example, following 1 hr at 60°C, complete stabilization was found even after holding 6 hr at −150°C.

Effect of Interrupting Subcooling below M_s: In order to determine the effect of interrupted subcooling, specimens were first cooled to intermediate subzero temperatures in the range of −70° to −80°C, held to produce various initial amounts of martensite, and then further cooled to and held at lower subzero temperatures. The results of this procedure (treatment *E*) are given in Fig. 4.

As shown in Fig. 4, the total amount of martensite formed by treatment *E* which involved interrupted subcooling to and isothermal holding at either −130°



TREATMENT A-RESULTS		
SUB-ZERO TEMP. T_1 OR T_2	TIME OF HOLD AT T_1 (OR T_2) t_1 (OR t_2)	TOTAL PCT MART-ENSITE
-70°C	30 MIN	2.5
-80°C	3 MIN	6
-80°C	1.5 HR	7.5
-130°C	0.6 MIN	19
-130°C	30 MIN	23
-150°C	30 MIN	26.5
-150°C	30 MIN	26.5
-197°C	30 MIN	19
-197°C	3 MIN	16
-197°C	2 HR	20

TREATMENT E-RESULTS				
INITIAL SUB-ZERO TEMP. T_1	TIME OF HOLD AT T_1 t_1	FINAL SUB-ZERO TEMP. T_2	TIME OF HOLD AT T_2 t_2	TOTAL PCT MART-ENSITE
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
-70°C	30 MIN	-130°C	0.6 MIN	19
-70°C	30 MIN	-130°C	30 MIN	23.5
-80°C	3 MIN	-150°C	30 MIN	25.5
-80°C	1.5 HR	-150°C	30 MIN	25.5
-70°C	30 MIN	-197°C	30 MIN	27.5
-80°C	1.5 HR	-197°C	3 MIN	7.5
-80°C	1.5 HR	-197°C	2 HR	19

Fig. 4—Effect of interrupting subcooling below M_s on total transformation following holding at −130°, −150°, and −197°C.

or 150°C, is approximately equal to that formed by treatment *A* which involved direct subcooling to and isothermal holding at these temperatures. Apparently, the initial amount of martensite such as was formed at −70° or −80°C does not affect the total amount of transformation obtained on cooling to and holding at −130° or −150°C.

On the other hand, the situation is different if a final subcool to −197°C is used. The formation of about 2.5 pct martensite by an interrupted subcooling at −70°C for 30 min actually results in a greater total amount of martensite after subsequent cooling to and holding at −197°C for 30 min (treatment *E*) than after direct cooling to and holding at this temperature for the same time (treatment *A*). It would seem that the formation of a small amount of mar-

a—Normal formation of martensite resulting from direct subcooling to and holding for 30 min at —197°C.

b—Burst formation of martensite resulting from subcooling to and holding 3 min at —80°C, cycling to 20°C, and finally subcooling to and holding 30 min at —197°C.

Fig. 5—Micrographs showing normal and burst formation of martensite. Etched with modified Villela's reagent. X250. Area reduced approximately 50 pct for reproduction.

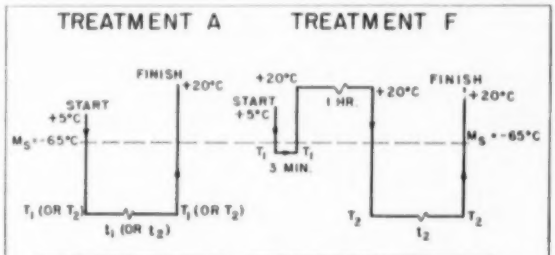
tensite by interrupted cooling has a stimulating effect on subsequent transformation on cooling to —197°C. However, if the amount of initial martensite is increased to about 7.5 pct by first cooling to —80°C and holding for 1.5 hr, essentially no further transformation takes place on subsequent cooling to and holding 3 min at —197°C. This indicates that the formation of a sufficiently large quantity of initial martensite can result in stabilization against further transformation on subsequent cooling to —197°C. However, if the time of holding at —197°C is increased from 3 min to 2 hr, the stabilizing effect of interrupted subcooling is overcome and approximately as much total martensite results as in the case of direct cooling to —197°C and holding for 2 hr. This is the same phenomenon that was observed as a result of treatment *D*, Fig. 3.

In order to study in more detail the stimulating effect associated with initial amounts of martensite, additional experiments were carried out. Specimens were subcooled to —70°C, held for 3 min to produce about 1 pct martensite, and finally cooled to —197°C. It was found that no further martensite formation occurred during the cooling to —197°C. However, on holding at —197°C for only 3 min about 14 pct martensite formed. This indicates that the stimulating effect is a complex phenomenon, first inducing stabilization against subsequent transformation on cooling from —70° to —197°C and then facilitating the formation of a relatively large amount of martensite on holding at —197°C for only a short time.

Microexamination of the specimens used in these experiments revealed that the small amount of martensite that formed during the initial subcool was mainly concentrated in the vicinity of the center of the specimen and was normal in appearance. On the other hand, the much larger amount of martensite that formed on holding at —197°C was found situated mainly in the region between the center zone and surface of the specimen. Furthermore this outer zone of martensite was found to possess a marked "zig-zag" appearance. It is believed that this type of martensite formation is due to the burst phenomenon reported by Machlin and Cohen[11] and Kulin.[12] The burst type of martensite formation was observed in all cases of stimulation associated with small initial amounts of martensite in the present investigation. Micrographs in Fig. 5 show the difference between normal formation and burst formation of martensite.

The normal formation shown in Fig. 5a, which resulted from direct subcooling to and holding at —197°C, is typical of the entire specimen area except for occasional "zig-zag" martensite configurations which occur to a minor extent. The burst formation shown in Fig. 5b, which resulted from interrupted subcooling followed by cycling prior to the final subcool to and hold at —197°C, is typical of the major portion of the specimen area except for a small region at the center which possesses a normal appearance. The effect of cycling following interrupted subcooling is discussed in more detail in the next section.

Effect of Cycling Following Interrupting Subcooling below M_s: In these experiments, specimens were cooled to a subzero temperature such as —80° or —90°C to form some martensite initially, reheated



TREATMENT A-RESULTS		
SUB-ZERO TEMP. T_1 (OR T_2)	TIME OF HOLD AT T_1 t_1 (OR t_2)	TOTAL PCT MART-ENSITE
-80°C	3 MIN	6
-90°C	3 MIN	11.5
-150°C	3 MIN	22.5
-150°C	2 HR	27.5
-150°C	3 MIN	22.5
-150°C	2 HR	27.5
-197°C	30 MIN	19
-197°C	24 HR	22
-197°C	30 MIN	19
-197°C	24 HR	22

TREATMENT F-RESULTS			
INITIAL SUB-ZERO TEMP. T_1	FINAL SUB-ZERO TEMP. T_2	TIME OF HOLD AT T_2 t_2	TOTAL PCT MART-ENSITE
—	—	—	—
—	—	—	—
-80°C	-150°C	3 MIN	20
-80°C	-150°C	2 HR	25
-90°C	-150°C	3 MIN	12
-90°C	-150°C	2 HR	25.5
-80°C	-197°C	30 MIN	27.5
-80°C	-197°C	24 HR	27
-90°C	-197°C	30 MIN	10
-90°C	-197°C	24 HR	15.5

Fig. 6—Effect of cycling at 20°C following interrupting subcooling below M_s on total transformation after isothermal hold at —150° and —197°C.

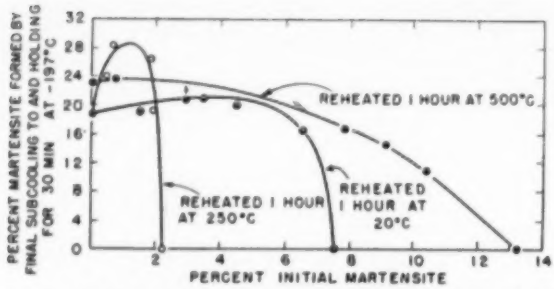

PERCENT MARTENSITE FORMED BY FINAL SUBCOOLING TO AND HOLDING FOR 30 MIN AT -197°C
PERCENT INITIAL MARTENSITE
REHEATED 1 HOUR AT 500°C
REHEATED 1 HOUR AT 250°C
REHEATED 1 HOUR AT 20°C

Fig. 7—Variation of amount of martensite formed by final subcool to −197°C with initial amount present and reheating temperature employed.

to 20°C, and finally cooled to −150° or −197°C. In Fig. 6 the effect of this cycling (treatment *F*) on total amount of martensite formed is compared with that of direct subcooling to and holding at the same final temperature (treatment *A*). Starting with 6 pct martensite (3 min at −80°C), cycling up to 20°C and back to −150°C results in a slightly lower amount of martensite as compared with treatment *A*. However, if the final subzero temperature is −197°C, a significant increase in total amount of martensite occurs. This indicates that it is possible to start with the same amount of martensite and incur either stabilization or stimulation depending on whether the final reaction temperature used is −150° or −197°C.

Variation of Critical Amount of Martensite with Reheating Temperature: Experiments were carried out to determine how the amount of initial martensite that is critical with respect to obtaining stimulation or stabilization is affected by reheating temperature. The procedure used is similar to treatment *F* except that reheating temperatures of 250° and 500°C as well as 20°C were employed. When reheating was carried out at temperatures of 250° and 500°C, the initial martensite was tempered but no transformation of the retained austenite took place. The tempering of the initial martensite provided a means of distinguishing in the same specimen between initial martensite and martensite formed on subcooling following the reheating treatment. The final subzero temperature used was −197°C and specimens were held 30 min at this temperature. The variation in the amount of initial martensite was produced by the initial treatments shown in Table I.

The results of reheating are shown in Fig. 7, which is a plot of amount of martensite formed subsequent to the initial treatment as a function of the amount of martensite initially present. These results confirm that for each temperature of reheating there is a critical limit of initial amount of martensite above which complete stabilization is induced against further transformation on subsequent subcooling to −197°C. For initial amounts of martensite below these limits, stimulation of the austenite apparently occurs and even more total martensite forms than for the case of zero initial martensite. These limits and the possible experimental errors are 7.5 ±1.5 pct, 2.5 ±1 pct, and 13 ±1 pct for reheating temperatures of 20°, 250°, and 500°C, respectively. Thus it appears that the critical limit first decreases with increase in reheating temperature from 20° to 250°C and then increases again somewhere in the range of 250° to 500°C.

Table I. Amount of Martensite Formed by Initial Subcooling Treatment

Initial Treatment	Range of Pct Martensite Formed
Cooled to −70°C and held for 3 min	Trace to 1
Cooled to −70°C and held for 30 min	1 to 3
Cooled to −80°C and held for 0 min	2 to 4
Cooled to −80°C and held for 3 min	4 to 7
Cooled to −90°C and held for 0.6 min	5 to 8
Cooled to −90°C and held for 3 min	10 to 13
Cooled to −100°C and held for 3 min	12 to 14

It was shown in Fig. 1 that by reheating to 500°C without any initial martensite present, there results an increase in the subsequent transformation on cooling to −197°C and this was attributed to the phenomenon of conditioning. It is also believed that the marked increase in critical amount of martensite required for complete stabilization using a reheating temperature of 500°C as compared to 250°C, as shown in Fig. 7, is also due to conditioning. This would mean that two opposing effects, stabilization and conditioning, occur as a result of reheating above about 250°C.

Discussion of Results

Relation of Partial Transformation to Stabilization: Whether partial transformation must occur before austenite can be stabilized against further transformation on cooling is still open to question. Although Harris and Cohen[13] and Machlin and Cohen[5] report that stabilization occurs only if the cooling is interrupted below M_s, Klier and Troiano[10] and DeLazaro et al.[14] report that stabilization can be induced if the cooling is interrupted above the M_s determined by continuous cooling. Attempts made in the present investigation to duplicate in detail the experiments of Klier and Troiano[10] on the same heat of 15 pct Cr-0.7 pct C steel failed to give the same results.

The reaction-path theory does not preclude the occurrence of stabilization as a result of interrupting the quench from the austenitizing temperature prior to cooling below M_s. If it is assumed that the distribution of strain embryos existing at the austenitizing temperature is retained on quenching to a temperature above M_s, relaxation of such embryos would not be expected to occur by the process of recovery. After all, these embryos survived exposure to the austenitizing temperature where recovery would be much more potent. It is possible, however, that relaxation could occur by diffusing of carbon atoms into strain embryo regions. At the high austenitizing temperature, the tendency for such clustering of carbon atoms would be opposed by the increased entropy associated with a random carbon distribution. After quenching to above M_s, the entropy effect would be reduced, and an overall decrease in free energy could result if carbon atoms diffuse into strain embryos. Such regions offer a greater amount of interstitial space than the more perfect regions of the lattice and a decrease in distortional energy would be expected. In order to account for the failure to observe stabilization in the present investigation as a result of interrupting the quench at room temperature or reheating the as-quenched austenite to as high as 250°C, it seems necessary to assume that the rate of diffusion of carbon in the austenite of the 15 pct Cr-0.7 pct C steel is too slow to have any appreciable effect in the temperature range studied.

On the other hand, stabilization was found to take place as a result of heating in the same temperature range provided that partial transformation of austenite to martensite had previously occurred. On the

basis that diffusion of carbon atoms into strain embryos results in relaxation, this would mean that for some reason the rate of diffusion of carbon in austenite is increased when some martensite is present. According to the reaction-path theory, generation of martensite plates results in the simultaneous formation of new strain embryos in the vicinity of these plates where both elastic and plastic deformation of the remaining austenite has occurred. Since the activity of carbon in martensite is presumably higher than in austenite even of the same composition, there would be a pronounced tendency for carbon atoms to diffuse from the edges of the martensite plates into strain embryos in the adjoining austenite.

Partial transformation appears to be a prerequisite for stabilization against both athermal and isothermal transformation of austenite to martensite. Stabilization against isothermal transformation was induced by first cooling to a subzero temperature below M_s and then cycling to 20°C or above before returning to the same subzero temperature for observance of isothermal transformation. It was found that the degree of stabilization increases with increase in both cycling temperature and time at a given cycling temperature. This would be expected on the basis that relaxation of strain embryos whether due to recovery or diffusion of carbon would be greater the higher the temperature or the longer the time.

Burst Formation: It has been shown that with small initial amounts of martensite formed by interrupting the subcool below M_s, it is possible to end up with more total martensite after subsequent cooling to and holding at −197°C than by direct subcooling to and holding at −197°C for the same length of time. This stimulating effect associated with small amounts of initial martensite is attributed to stabilization against transformation on subsequent cooling to −197°C followed by burst formation at this temperature. Stabilization as induced by interrupted cooling below M_s may be due to a decrease of high energy strain embryos resulting from both relaxation and isothermal transformation. In view of the small amount of isothermal transformation involved, it seems likely that relaxation plays the major role in inducing stabilization.

The burst phenomenon has been described by Machlin and Cohen.[12] The activation of a sufficient number of strain embryos simultaneously either during cooling or at constant temperature is believed to create sufficient momentum to start a chain reaction. This results in a relatively large increment of transformation occurring practically instantaneously. The temperature at which this phenomenon first occurs on cooling is called the martensite burst point and is designated as M_b. It is apparently necessary to cool the austenite of the 15 pct Cr-0.7 pct C steel to approximately −197°C in order to lower the activation energy sufficiently to facilitate burst formation of martensite.

In the present investigation it was found that the tendency for burst formation is markedly inhibited if the initial martensite content exceeds a critical amount. Interrupting the subcool below M_s results in initial formation of martensite in the region of the center of the specimen. This location is to be expected since the specimen in the as-quenched condition has a residual stress distribution varying from compression at the outside to tension at the center, and Kulin[12] has shown that martensite formation is aided by residual tension and hindered by residual compression. With increase in the amount of martensite that is allowed to form as a result of the initial subcool, the zone of transformation which has a normal appearance spreads out from the center of the specimen. When the specimen is subsequently cooled to −197°C, it is observed that burst formation is restricted to the remaining rim of untransformed austenite. By allowing the formation of sufficient initial martensite, it is possible to virtually eliminate the untransformed rim and thereby suppress burst formation of any appreciable magnitude on subsequent cooling to and holding at −197°C.

That burst formation is mainly restricted to the rim of untransformed austenite is probably due to the constraints resulting from subdivision of austenite by the martensite plates formed initially at the center zone of the specimen. The degree of cooperation required for burst formation is probably lowered by the obstructing action of martensite plates with respect to the propagation of strain associated with a burst. These plates probably act as the walls of partial enclosures in which triaxial compressive stresses are set up when a transformation strain is encountered. Kulin[12] has shown that such a stress condition externally applied to the specimen as a whole can result in a lowering of both M_s and M_b.

It was found that the critical amount of initial martensite required for complete suppression of burst formation over a period of 30 min at −197°C decreases as a result of intermediate cycling to increasing temperatures up to about 250°C. By cycling to 250°C, the critical limit was reduced to about 2.5 pct, which is not a sufficient amount to allow the central zone of normal martensite to encompass the entire volume of the specimen. In this case, the failure to observe the occurrence of burst formation in the untransformed rim may be due to the high degree of relaxation resulting from heating to 250°C. Sufficient relaxation of strain embryos situated at the outside fringes of the center zone of normal martensite formation might prevent them from triggering off bursts on subsequent cooling to and holding at −197°C.

Disappearance of Stabilization: As has been previously discussed, stabilization induced by interrupting the subcool below M_s is more pronounced the greater the initial amount of martensite formed prior to cooling to and holding at the final subzero reaction temperature. With small amounts of initial martensite, stabilization is apparently overcome in very short periods of time at −197°C by burst formations of relatively large magnitude which occur discontinuously. With larger amounts of initial martensite exceeding what is called the critical limit, stabilization seems to be more permanent. However, after sufficient time at the final reaction temperature, the stabilization effect tends to disappear. Disappearance of stabilization is manifest by isothermal formation of martensite starting after what may be either an incubation period or else a period during which the rate of transformation is too slow to be detected with the metallographic method employed. If the holding time at the final reaction temperature is sufficiently long, the original handicap in martensite content can apparently be overcome and about the same total amount of transformation results as formed by direct cooling to and holding at the same reaction temperature for the same period of time. However, the higher the cycling temperature used prior to cooling to the final

reaction temperature, the more permanent is the stabilizing effect.

In the previous investigation the authors found that the rate of isothermal transformation is maximum at the start and then decreases with time. According to the reaction-path theory, the initial rate of isothermal transformation is maximum because at zero time the distribution of strain embryos is most favorable; with increase in time the higher energy embryos are used up in generating martensite and the rate decreases.

Apparently the situation is different with respect to isothermal transformation following stabilization since the initial rate is definitely not maximum and may even be zero. The results of microexamination of specimens in which disappearance of stabilization occurred indicate that this phenomenon may be due to both normal and burst formation of martensite. Machlin and Cohen[13] report the occurrence of a series of bursts either with or without periods of gradual transformation at constant temperature. Such a complex behavior is difficult to analyze.

Conditioning: On reheating to temperatures of above 250°C, the phenomenon of conditioning is encountered. This results in more martensite being formed at a subzero temperature than is the case for subcooling without an immediate reheating treatment. Conditioning appears to occur whether or not some martensite is initially present.

In the tempering of high speed steel, conditioning of the retained austenite results from precipitation of carbides which lowers the carbon and alloy content of the austenite and makes it susceptible to transformation to martensite on cooling from the tempering temperature to room temperature. No actual precipitation of carbides from austenite was observed microscopically as a result of heating the 15 pct Cr-0.7 pct C steel to temperatures as high as 500°C; however, it is believed that local changes in chemical composition on a microscopic scale do occur in preparation for formation of isothermal products such as bainite. These segregations within solid solution could yield low carbon regions which are more unstable with respect to transformation into martensite than high carbon regions. On cooling, the low carbon regions should facilitate martensite formation and thus yield a greater amount of transformation on reaching low subzero temperatures. Since both conditioning and stabilization tendencies become stronger the higher the temperature of reheating, the actual martensite formation on subsequent subcooling depends on the relative potency of the two opposing effects.

Summary

The results of this investigation of the austenite-martensite reaction in a 15 pct Cr-0.7 pct C steel are as follows:

1—No appreciable stabilization against athermal or isothermal transformation results unless partial transformation has occurred previously.

2—By interrupting the subcool below M_s and forming small amounts of martensite, stabilization is induced on subsequent cooling. If the final cooling is to −197°C, burst formation of martensite results on holding for very short times at this temperature.

3—When the amount of martensite as formed by interrupting the subcool below M_s exceeds a critical limit, the stabilization effect induced on subsequent cooling to low subzero temperatures is more marked. However, disappearance of the stabilization effect eventually occurs on continued holding at such temperatures.

4—For a given amount of initial martensite, the higher the temperature of intermediate cycling the more permanent is the stabilization effect at the final subzero reaction temperature.

5—Appreciable conditioning of retained austenite results from reheating to about 500°C with or without the existence of prior transformation.

The reaction-path theory has proved extremely fruitful in providing general explanations for the above phenomena.

Acknowledgments

The authors wish to thank the Union Carbide and Carbon Corp. for the pre-doctoral fellowship and the Studebaker Corp. for the financial aid which made this work possible. The assistance of Professor Morris Cohen in the interpretation of the experimental results on the basis of the reaction-path theory is gratefully acknowledged.

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Effects of Macrostructure on the Performance Of Alnico Permanent Magnets

by Dolph G. Ebeling and Arthur A. Burr

The effects of casting texture, grain orientation and grain size upon the performance of Alnico permanent magnets is described. Single-crystal specimens were produced by special sintering and grain coarsening techniques to study the effect of crystal orientation. In addition to texture and orientation effects, an analysis of the results indicates that the permanent magnet performance is impaired by a refinement of the grain size.

AN excellent historical review of the development of Alnico permanent magnets has been prepared by Bozorth.[1] The desirable permanent magnet characteristics of Fe-Ni-Al alloys were discovered in 1932 by Mishima.[2, 3] The work of Ruder[4] showed that the alloys were age-hardenable, and Betteridge[5] defined the best composition and heat treatment for the magnetically isotropic alloy known as "Alnico 3." Horsburgh and Tetley[6] increased the energy product by the addition of cobalt and copper, "Alnico 2," and Oliver and Sheddon[7] demonstrated that cooling in a magnetic field improved the residual induction of this alloy. Jonas[8, 9] then disclosed the great practical benefits of heat treating an alloy of higher cobalt content in a magnetic field and the resulting alloy, "Alnico 5," has become the standard of the industry. This paper describes the fundamental aspects of a procedure which can be used to further improve the properties of these anisotropic permanent magnet alloys.

A study of the casting techniques used in the production of anisotropic Alnico permanent magnets indicated that the magnetic quality was affected by the as-cast macrostructure. Improved performance was observed in magnets containing a high percentage of columnar grains whose long axes were parallel to the magnetic axis of the casting. McCaig[10] studied the effect of such columnar grain structures upon the magnetostriction characteristics of similar alloys, however no data was presented showing the effects on other magnetic properties. The following paragraphs describe two experiments which were conducted to determine the effect of various grain orientations upon the energy product.

Special composite molds were prepared of highly conductive and highly refractive components to remove the heat of solidification from the casting in a controlled manner. Representative macrostructures produced by these techniques are shown in Fig. 1, along with the relative volumes of favorably oriented columnar grains. The alloy, Alnico 5, has the highest permanent magnet performance of any commercial magnet material. It has the nominal weight composition of 8 pct Al, 14 pct Ni, 24 pct Co, 3 pct Cu, and 51 pct Fe. A heat of this material was cast into molds producing the type A and B grain structures shown in Fig. 1 and pairs of the resulting magnets were placed in heat-treating boats so as to eliminate any biasing effects of boat position. After a standard heat treatment the type A magnets, with 16 pct of the volume composed of favorably aligned grains, had a maximum energy value of 3,940,000 gauss-oersteds, while the type B magnets with 73 pct aligned grains averaged 5,090,000. This large im-

D. G. EBELING, Member AIME, is associated with the Research Laboratory, General Electric Co., Schenectady, and A. A. BURR, Member AIME, is Associate Professor of Metallurgy, Rensselaer Polytechnic Institute, Troy, N. Y.

Discussion on this paper, TP 3433E, may be sent, 2 copies, to AIME by Dec. 1, 1953. Manuscript, April 16, 1952. Cleveland Meeting, October 1953.

This paper is based on a thesis by D. G. Ebeling submitted in partial fulfillment of requirements for a Doctor of Philosophy degree to the Department of Metallurgical Engineering of Rensselaer Polytechnic Institute.

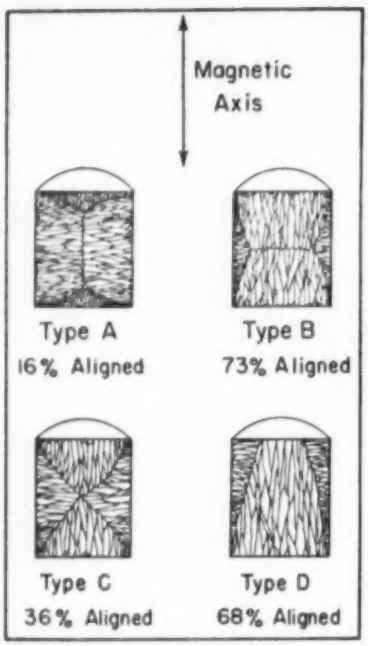

Fig. 1 — Macrostructures developed in directionally chilled, cylindrical castings of Alnico.

provement was obtained with a 57 pct increase in the volume of aligned grains, which indicated a difference of two million in the energy product between the fully aligned and fully unaligned macrostructures.

In another experiment, a portion of an 800 lb heat of Alnico 5 was cast into two types of molds so as to produce magnets of the types C and D shown in Fig. 1. A total of 236 pairs of these magnets were heat-treated in such a manner as to eliminate any spurious effects of loading. The results showed that the type C magnets with 36 pct of the volume composed of favorably aligned grains had a maximum energy value of 4,470,000, while the type D magnets with 68 pct aligned grains averaged 4,950,000. This 480,000 improvement in energy was realized with a 32 pct increase in the volume of aligned grains. This ratio extrapolates to a one and one-half million energy change between the two extreme types of macrostructure. Other experiments substantiated these indications of an important crystallographic factor affecting the quality of these permanent magnet alloys and after a study of the production aspects of the problem, a means of achieving controlled macrostructures was successfully reduced to practice.[11] Although the beneficial effects of certain grain structures had been demonstrated, it was of interest to establish an explanation for this behavior.

Theory

Two explanations were proposed for the previous observations. To facilitate a discussion of these proposals it is appropriate to review the magnetic characteristics that are important in the evaluation of permanent magnet materials. For this purpose, reference is made to Fig. 3.

B_f: The "ferric induction" is the peak induction, or B value, minus the peak magnetizing field, or H value.

B_r: The "residual induction" is the magnetic induction corresponding to zero magnetizing force after the material has been magnetized to saturation.

H_c: The "coercive force" is the magnetizing force required to bring the induction to zero after the material has been fully saturated.

BH_m: The "maximum energy" is the commonly accepted criterion of the excellence of a permanent magnet, and it is the product of B and H at the point in the demagnetization curve where this product is a maximum.

C: The "curvature ratio" is a dimensionless number which serves as a useful measure of the squareness of the hysteresis loop and it is defined by the relation: $C = \frac{BH_m}{B_f \cdot H_c}$.

This relationship emphasizes the simple dependence of the magnet quality on three basic factors, namely: 1—The ferric induction which is controlled by the chemical composition; 2—the coercive force which is largely dependent upon the structures and lattice strains developed by the precipitation hardening reaction; and 3—the curvature ratio which will be shown to be related to crystallographic factors, such as grain orientation and grain size. In terms of these basic parameters the principal effect of the favorably oriented macrostructures was found to be an increase in the curvature factor, that is to say, to produce a square-shaped hysteresis loop. The proposed explanations of these columnar grain effects will now be presented.

In one hypothesis it was assumed there was a crystallographic "direction of easy magnetization" in these permanent magnet alloys. Single-crystal studies have shown that hysteresis curves measured in the direction of easy magnetization are rectangular in shape, whereas measurements in other crystallographic directions produce skewed hysteresis loops.[12-14] The high curvature factors and energy values of these directionally chilled Alnico magnets could be explained if the crystallographic textures developed in these chilled castings corresponded to the direction of easy magnetization. There were good grounds for this supposition since all body-centered cubic metals solidify with [100] casting textures and this is just the direction of easy magnetization in soft magnetic alloys having a body-centered cubic structure.

The second explanation of the columnar grain effects was based upon different grounds. Aside from the postulated difference in texture, the macrostructures shown in Fig. 1 differ greatly in the number of grain boundaries intercepted by the magnetic axis. At each grain boundary, the stable direction of magnetization must change and, hence, the internal magnetic path must be discontinuous. In magnets composed largely of favorably aligned columnar grains there are fewer interruptions in the domain path than in an unfavorably aligned structure. Intuitively, it appears that the fewer the interruptions, the more stable will be the resulting domain configuration. This paper describes an investigation which was conducted to examine the validity of these proposed mechanisms.

Procedure

Single crystals were required to study this problem. The standard techniques for growing single crystals from the melt and in the solid state were applied to these alloys without success. Crystal growth from the melt had been found impractical due to the excessive loss of aluminum while holding these 8 pct Al alloys in the molten state for a period of time

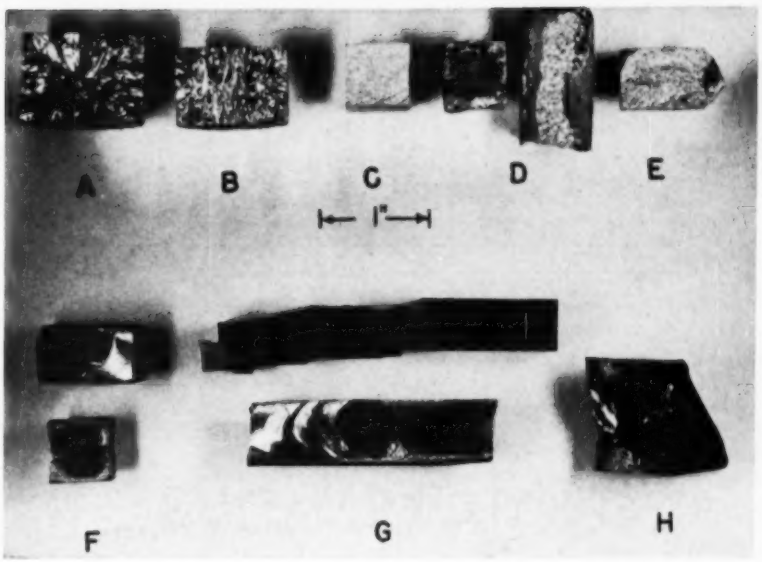

Fig. 2 — Examples of macrostructures produced in cast and sintered Alnico.

A. Normal as-cast structure produced by sand mold
B. Directional grain structure produced in mold by the use of metal chills at the pole faces
C. Normal sintered structure
D. First sintered crystal showing distorted surface, cavities and fine grained skin
E. Longitudinal fracture showing initiation of massive crystal growth
F. Typical fractures in sintered crystals
G. Fractures in sintered crystals indicating extent of grain growth
H. Crystal developed in a sintered bar of ¾x1 in. cross section

sufficient to grow massive crystals. Grain growth in the solid state did not appear promising, since prolonged exposure to high temperatures resulted in only slight grain coarsening.

An investigation of the powder metallurgy technique was then conducted, since abnormal grain growth had been observed in a few samples of sintered Alnico 5. In the first experiment a heat of 50 pct Al-50 pct Co was prepared in a small induction furnace and subsequently reduced to −200 mesh powder. This powder was made into an Alnico 5 mix and pressed into ½x½x3 in. test bars. These bars were placed in sintering boats containing burnt alumina powder and mechanically pushed through a hydrogen atmosphere sintering furnace at such a rate that the bars were at a maximum temperature of 1380°C for 4.5 hr. These bars were fractured after sintering and all but one exhibited the normal, fine-grained macrostructure. As shown in Fig. 2 this remaining specimen contained a massive crystal surrounded by numerous cavities and a badly distorted, fine-grained surface layer. Microscopic examination revealed a fine, flocculent white powder on the surface of these voids which was taken to be alumina.

To minimize the formation of oxide films at the particle boundaries, an attempt was made to reduce the oxygen content of the powder compact. Two additional Al-Co heats were melted; in one the Al:Co ratio was 50:50 while in the other it was 25:75. These heats were ball-milled to −200 mesh under liquid toluene in which was dissolved a small amount of paraffin. The toluene was added to minimize oxidation during milling and the paraffin was expected to provide protection against oxidation during subsequent handling and pressing operations. Bars were prepared from these mixes and, after sintering, it was found that all the bars containing the 50:50 mix were fine-grained, porous, and distorted, whereas the 25:75 mix produced bars having smooth surfaces, practically no distortion, and massive crystals. There was still a thin layer of fine-grained material on all external surfaces which varied in thickness from 0.010 to 0.050 in. This performance was repeated a number of times and, at one point, 48 out of 50 consecutive bars developed massive crystals.

Having achieved a successful method of producing large crystals, several subsidiary investigations were conducted. A study of the sintering times showed that the growth of the massive crystals occurred in only 30 pct of the bars if the time at temperature was reduced from 4.5 to 2.6 hr. Other experiments were conducted to eliminate the thin surface layer of fine-grained material. Surface treatments, protective shields, and the addition of "getters" to the burnt alumina were investigated and although getter powders were partially effective, this fine-grained skin was never completely eliminated. In all subsequent work this thin surface layer was removed by surface grinding.

The orientations of a large number of grains were determined by X-ray methods to learn if there were any possibility of controlling the orientation of the large crystals. It was found that no characteristic textures were developed about either the pressing or sintering directions. In view of these results, larger compacts were prepared and single-crystal

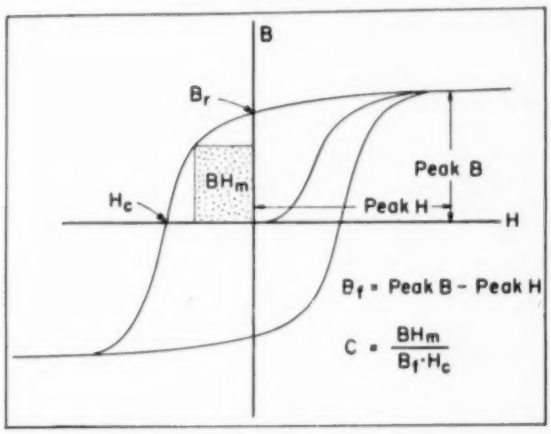

Fig. 3—Hysteresis curve showing the properties of interest in permanent magnet materials.

Table I. Sintered Alnico 5

Test No.	16	17	18	19	20
Specimen	1	2	3	4	5
Orientation*	0°–0°	10°–7°	22°–13°	21°–15°	27°–12°
B_f	13,100	13,200	13,100	13,175	13,100
B_r	12,300	12,400	11,950	12,125	11,800
H_c	700	685	665	665	650
C	0.69	0.69	0.60	0.59	0.59
$BH_m \times 10^{-6}$	6,320	6,200	5,280	5,200	5,050

* Angles (a-b) in Fig. 4.

specimens of suitable size and orientation were obtained by cutting and grinding operations.

These larger bars measured about ¾x1x7 in. Upon removing the fine-grained skin they were found to contain a number of large grains. The surfaces were polished and etched to delineate the grain boundaries and the orientations of the individual grains were determined by the Laue technique. All sides of each crystal were ground on a surface grinder to obtain the parallel faces which were necessary for accurate magnetic testing. These crystals fractured on the cube planes very readily and great care was required to avoid overheating or stressing during the cutting and grinding operations. The final specimens were not identical in shape but a representative size was ¼x⅜x¾ in. Laue photograms were taken on each end of each specimen to determine the orientation of the magnetic axis and to detect the presence of any spurious grains.

These crystals had to be heat-treated in a magnetic field to develop their maximum magnetic properties. Above the Curie temperature the permeability of Alnico is roughly that of air and the magnetic lines of flux inside the directionalizing coil are essentially parallel. Upon cooling below this temperature the permeability of the Alnico increases sharply and this causes the lines of flux to be focused toward the higher permeability material. If not corrected, the divergent flux pattern created at the ends of the magnet would cause the material to be permanently directionalized in this manner with a resulting loss in performance. To combat this condition, Alnico pole pieces were placed at the ends of the magnets to concentrate the lines of flux and focus a parallel magnetic field on the magnet under treatment.

Each crystal with its carefully matched pairs of Alnico 5 pole pieces was aligned in a heat-treating boat, blocked in position with pieces of firebrick, and covered with sufficient burnt alumina to provide the proper cooling rate in the magnetic treatment. Unless otherwise noted, the heat treatment consisted of a 30 min, 1300°C solution treatment in a hydrogen atmosphere followed by a cooling treatment in a magnetic field of 1400 oersteds under such conditions that the cooling rate in the region from 1100° to 800°C was about 100°C per min. These crystals were removed from the field when black and aged at 600°C for 6 hr. Finally, the crystals were demagnetized, polished, dimensioned, and prepared for test by carefully wrapping and cementing a "B" coil about the center cross section of the specimen. The magnetic tests were conducted in an electromagnet using a standard magnetizing field of 3000 oersteds.

Near the end of this program, it was found possible to grow large single crystals in two cast materials having compositions which differ from the straight Alnico 5 by the addition of minor amounts of titanium, silicon, and zirconium. The addition of a few percentages of titanium to Alnico 5 greatly increases the coercive force, and this high coercivity grade is commonly known as Alnico 6. The other

Table II. Sintered Alnico 5

Test No.	42	43	44
Specimen	11	12	13
Orientation	40°–0°	6°–2°	0°–0°
B_f	13,100	13,500	13,450
B_r	11,600	12,700	12,650
H_c	589	659	662
C	0.54	0.66	0.67
$BH_m \times 10^{-6}$	4,200	5,900	6,000

modification of Alnico 5 is achieved by the addition of minor amounts of silicon and zirconium.[15] These additions retard the precipitation hardening reaction to such an extent that overaging of the casting while cooling in the sand molds is prevented and therefore the 1300°C solution treatment is not required.

The production of large grains in castings of these modified compositions warrants comment, since this had not been possible in the case of the straight Alnico 5. In addition to their other specific effects, the titanium, zirconium, and silicon additions in these alloys tend to refine the as-cast grain size, presumably as a result of the nucleation effects of compounds formed by these elements. The resulting increase in the grain boundary area greatly increases the grain boundary energy responsible for grain growth, and it also reduces the concentration of impurities in these grain boundaries. This increase in grain boundary energy coupled with the decreased resistance to growth offered by the less contaminated boundaries is believed responsible for the formation of the massive crystals. This view of the abnormal grain growth experienced in these materials is supported by the behavior of the relatively fine-grained, sintered Alnico. In this case, the grain boundary area is extremely large and the impurity content of the boundaries is low because there is no segregation

Table III. Sintered Alnico 5

Composition in Wt Pct	Al	Ni	Co	Cu	Si	Zr	Ti	Fe
	8.24	13.75	20.88	3.20	0.02	0.00	0.00	Balance
Test No.			45	46	47	48	49	50
Specimen No.			14	15	16	17	18	19
Orientation			45°–0°	43°–2°	43°–1°	44°–1°	2°–0°	44°–35°
B_f			13,400	13,300	13,400	13,800	13,550	13,500
B_r			11,400	11,500	11,600	11,700	12,650	11,300
H_c			559	540	550	562	648	541
C			0.53	0.57	0.57	0.55	0.68	0.51
$BH_m \times 10^{-6}$			3,990	4,100	4,200	4,300	6,000	3,750

of foreign atoms such as occurs during the selective solidification of a melt. The necessity for the extreme precautions against surface contamination of the powder particles may also be explained in terms of this impurity concept.

Results

The data obtained in this work is presented so as to show the correlation between the crystallographic orientation of the magnetic axis and the various magnetic properties. For this purpose, the orientation of the magnetic axes in these single crystals is represented by a point in the unit stereographic triangle. The coordinates of this point are given by a pair of angles (a-b), the first measured along a [100] zone from the [100] pole to the meridian of the magnetic axis, while the second angle is measured along this meridian between the magnetic axis and this [100] zone, Fig. 4.

Sintered Alnico 5 Crystals: One set of five crystals was cut from sintered bars made from the same mix; these pieces were heat-treated simultaneously and tested in the direction of the magnetic field during heat treatment with the results shown in Table I. These results show a large variation in the maximum energy value as the angle between the magnetic axis and the cube pole is increased. The 25 pct variation in the maximum energy can be attributed primarily to the change in the curvature factor, since the saturation values are unchanged and the coercivity is increased by only 8 pct.

Eighteen additional determinations were obtained on crystals of random orientations, and while the data confirmed the trend toward high values in the [100] region and low values near the [111] axis, there was some scatter in the results. This variation was due partly to the fact that the specimens did not come from the same mix and had not been sintered or heat-treated at the same time. There was an abnormal variation in the ferric induction values and this was traced to a significant variation in the density of the specimens. Microscopic examination revealed minute voids in these sintered single crystals and this porosity accounted for the variations in density which ranged between 94.4 and 98.7 pct of the theoretical value.

At this point in the program the crystal preparation techniques had improved, and it was possible to cut specimens with any desired orientation. The orientations of major interest were at the corners of the unit triangle and the next set of crystals afforded a comparison of a cube oriented specimen with one having nearly a [110] orientation. The detailed results are given in Table II and they demonstrate the appreciably greater curvature and maximum energy values associated with the cube orientation.

To amplify these results another set of six specimens was prepared which covered the three principal crystallographic directions. These crystals were cut from adjacent grains of the same sintered bar so the chemical compositions and the pressing and sintering conditions were identical for all specimens. They were heat-treated simultaneously using six sets of carefully matched flux collectors. The results of the wet chemical analyses taken on pieces of these crystals and the magnetic data are summarized in Table III.

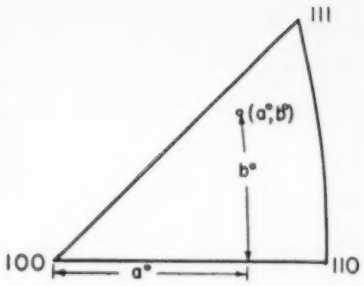

Fig. 4—Unit stereographic triangle showing the coordinate system used to identify the orientation of the magnetic axis.

Table IV. Cast Alnico 6

Al	Ni	Co	Cu	Si	Zr	Ti	Fe
6.68	14.64	23.16	3.09	0.08	0.00	1.65	Balance

Test No. / Specimen No.	51 / 1	52 / 2	53 / 3	57 / 31	59 / 32
Orientation	2°–1°	5°–0°	4°–2°	44°–34°	Fine grain
B_f	14,100	14,000	13,800	12,700	13,200
B_r	12,600	13,000	12,700	9,800	10,600
H_c	765	740	745	690	684
C	0.60	0.63	0.63	0.33	0.44
$BH_m \times 10^{-6}$	6,500	6,550	6,450	2,900	4,000

Table V. Cast Alnico 5

Al	Ni	Co	Cu	Si	Zr	Ti	Fe
7.79	13.61	22.99	2.07	0.43	0.27	0.00	Balance

Test No. / Treatment	64 / 900° and 600°C	65 / Plus 1300° and 900° and 600°C
Orientation	2°–1°	2°–1°
B_f	14,350	14,300
B_r	12,650	13,700
H_c	608	690
Pct C	0.46	0.71
BH_m	3,980,000	7,020,000

Cast Alnico 6 Crystals: The fracture of a large Alnico 6 casting indicated that grain coarsening had occurred in one section of the piece during heat treatment at 1260°C. This casting was surface ground, polished, and etched to reveal several large grains from which suitable single-crystal specimens of the desired orientations were obtained. In addition, a similar shaped specimen was prepared from a fine-grained portion of the same casting. The chemical and magnetic results are given in Table IV.

The same orientation effects are found in this material as in the case of the sintered Alnico 5, however, the difference between the highest and lowest energy values is greater: 3,650,000 for Alnico 6 vs 2,250,000 gauss-oersteds, in the case of Alnico 5.

Cast Alnico 5 Crystals: In view of the previous results, an attempt was made to develop the ultimate properties of an Alnico permanent magnet. The Si-Zr modification of Alnico 5 was selected for this purpose because this material has a higher intrinsic magnetization than either the porous sintered Alnico 5 or the titanium-bearing Alnico 6. A large casting of this material was subjected to a grain coarsening treatment which consisted of 12 hr at 1300°C followed by 50 hr at 1200°C. This treatment produced large grains from which were obtained two single-crystal specimens. When the 900°C directionalizing treatment was applied to these specimens, the resulting energy product was very low, possibly as a

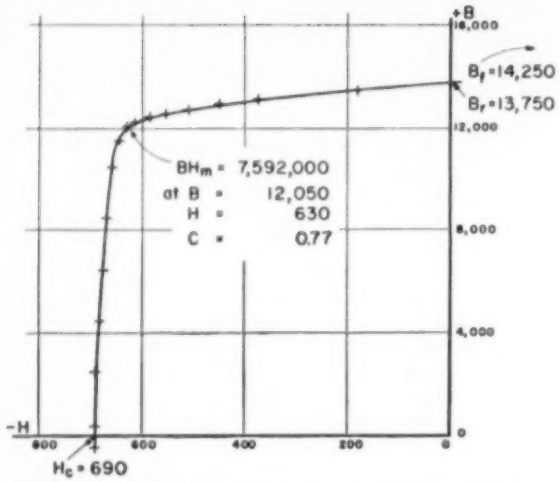

Fig. 5—Demagnetization curve obtained on a single crystal of cast Alnico 5-S.

result of excessive precipitation during the 1200°C coarsening treatment. Consequently, the material was subjected to a 1300°C solution treatment which was followed by another 900°C directionalizing treatment and a 6 hr age at 600°C. The results obtained on the more favorably oriented crystal after these treatments are given in Table V.

Although this seven million energy value was about 50 pct greater than the normal values obtained on this material, an attempt was made to improve the performance still further. In the course of this and other investigations on Alnico magnets, it was found that very deleterious surface conditions could be developed on magnets by prolonged exposures to high temperatures. Microscopic examination of these layers showed that they were heavily precipitated and such a structure is known to produce a very low coercive force. The existence of such a surface layer appeared likely on this reheat-treated specimen, so 0.020 in. was ground off all sides of this crystal. The following results were obtained on this reground specimen: B_f, 14,250; B_r, 13,750; H_c, 690; C, 0.77; and BH_m, 7,590,000. The actual test results are presented in Fig. 5, which illustrates the extreme "squareness" of the demagnetization curve. The curvature ratio of 0.77 was the highest observed in this work, as was the energy value of 7,590,000 gauss-oersteds.

Cast Textures: A large cylindrical slab of Alnico 5 approximately 10 in. in diameter and 2 in. thick was cast using a metal chill on the bottom surface. A uniformly oriented, columnar grain structure was produced in the center of this casting and the individual grains were of sufficient size to obtain Laue photograms. The orientations of the prominent grains in a sample cut from this structure were determined by James[5] and the results are reproduced in Fig. 6 in the form of a distribution plot showing the orientation of the cooling direction in the various grains of this directionally chilled casting. The concentration of points near the cube pole, particularly those obtained on the ten longest columnar grains, demonstrates the existence of a cube texture in these directionally chilled castings.

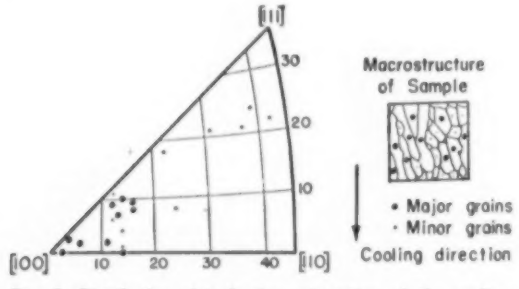

Fig. 6—Distribution plot showing orientation of the cooling direction in a directionally chilled casting.

Discussion

Crystal Orientation Effects: The results of the investigations on sintered Alnico 5 and cast Alnico 6 are summarized in Table VI.

These values conclusively demonstrate the dependence of the curvature ratio and the coercive force upon the orientation of the magnetic axis. Further, since both of these properties increase simultaneously in the region of the cube direction, there results a very marked improvement in the maximum energy. Although the table adequately summarizes these data, it was of interest to pursue the analysis to establish if the high and low values are approached asymtotically or whether there are cusps in the energy function. For this purpose, the data contained in Tables I to III were plotted on the unit stereographic triangle. Each set of data indicated a slow approach to the maximum value of the energy at the cube pole, but the data in the region of the octagonal pole were not conclusive.

Table VI. Crystal Orientation Effects

Magnetic Axis	Maximum Energy Gauss Oersteds	Ferric Induction Gauss	Coercive Force Oersteds	Curvature Ratio
Sintered Alnico 5				
[100]	6,000,000	13,550	650	0.68
[110]	4,100,000	13,500	550	0.55
[111]	3,750,000	13,500	540	0.51
Cast Alnico 6				
[100]	6,500,000	14,100	750	0.62
[111]	2,900,000	12,700	690	0.33
Fine Grain	4,000,000	13,200	680	0.44

When a saturating magnetizing field is removed, the directions of magnetization in the individual domains tend to return to the crystallographic axes of maximum stability, [100] in this case. If a cube axis is aligned with the direction of the magnetizing field, there will be relatively little loss in induction when the field is removed. Conversely, there will be a significant loss in induction if the crystallographic directions of easy magnetization are inclined at an appreciable angle to the axis of the magnetizing field. This concept suggests that the induction for any value of the applied field—and hence the energy product—should decrease continually as the angle between the magnetizing field and the crystallographic axis of easy magnetization is increased. Fig. 7 shows the result of fitting the simplest function of this type to the data obtained on all the Alnico 5 specimens. The scatter in the results is not excessive in view of the fact that the plot includes three separate sets of crystals which might be subject to composition and heat-treatment differences. This cosine relationship was adopted in the construction of a contour plot showing the variation in energy for all

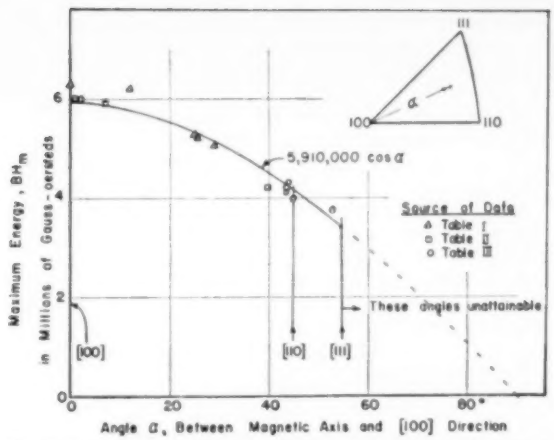

Fig. 7—Correlation of maximum energy values with the orientation of the magnetic axis in sintered crystals of Alnico 5.

intermediate orientations, Fig. 8. The nature of this energy relation is such as to produce flat maximums at the cube poles, saddles at the diagonal poles, and low cusps at the octagonal poles. This same construction was applied to the Alnico 6 data, and on the basis of the limited data, it appeared that the magnetic properties fell off somewhat more rapidly than a simple cosine law.

Grain Size Effects: Having obtained an estimate of the magnitude of the crystal orientation effects an attempt was made to apply these relationships to other phases of the problem. There is no preferred

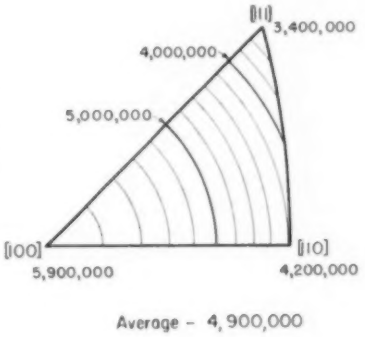

Fig. 8—Contour plot showing relative values of the maximum energy for various orientations of the magnetic axis in sintered crystals of Alnico 5.

orientation in the fine, equiaxed grain structure of the normal sintered material which has an average grain diameter of 0.15 mm or an ASTM grain size of 2 to 3. Thus, if no factors other than the crystallographic orientation are involved, then the maximum energy of this material should be equal to the average value of the energy surface shown in Fig. 8. A mean value of 4,900,000 gauss-oersteds was obtained by a graphical integration of this figure in which the lateral contraction of the stereographic plot was considered by multiplying the unit areas by the cosine of the latitude. The fact that this calculated value is so much greater than the value of 3,500,000 usually obtained for sintered material suggests that a fine-grain structure may be detrimental *per se*, a conclusion which has been suggested by other observations.

For example, a similar analysis using a cast Alnico 6 contour plot yields an average value of 4,780,000 gauss-oersteds for randomly oriented polycrystalline material. This compares with a maximum energy of only 4,000,000 as measured on the fine-grained cast Alnico 6 specimen which had an average grain diameter of 0.5 mm, ASTM grain size −1, and is additional evidence of a detrimental grain size effect. This behavior is rationalized on the basis of the inherent instability of a fine-grained, multidomain structure. In such a structure the misalignment of the directions of easy magnetization between the neighboring grains will facilitate the formation of closed magnetic circuits within the material with a corresponding loss in the useful induction.

Columnar Grain Effects: In the light of these investigations it was of interest to review the original experiments on the columnar grain structures. The grain orientation survey definitely indicated the existence of a cube texture in this material. Actually a perfect alignment is not obtained in any cast texture, but rather the cube axes of all the grains will be distributed about the cooling direction. To characterize the degree of concentration of the cube axes about any given direction, it is convenient to think in terms of an equivalent, uniform distribution of cube axes confined to a cone of revolution about this chosen axis. The degree of concentration can be represented as the half angle of the cone which is required to produce the same resolved component of the [100] axes on this reference axis as exists in the actual casting. On the basis of the distribution plot presented in Fig. 6, it is estimated that the columnar grain structures could be represented by a half angle of 15°. Using this concept and the stereographic contour plots, the theoretical estimates of the fully aligned and the fully unaligned columnar grain structures can be compared. As shown in Fig. 9, the fully aligned structure would be represented by the average of all the energy values within a 15° cone about the [100] axis, while the cross aligned specimen would encompass all values within a 15° band on either side of the [100] zone. Using the same averaging procedure as before, the contour plots gave the values shown in Table VII.

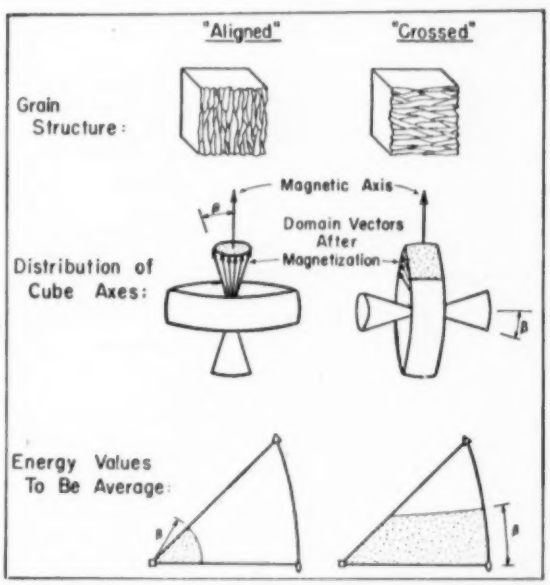

Fig. 9—Method of estimating the relative energy values of two extreme types of columnar grain structures.

Table VII. Estimates of Columnar Grain Effects

Material	Fully Aligned	Cross Aligned	Difference
Alnico 5	5,790,000	5,180,000	610,000
Alnico 6	6,190,000	5,150,000	1,040,000

These crystallographic considerations predict an energy difference of a million gauss-oersteds or less between a casting composed completely of long columnar grains parallel to the magnetic axis and one in which all the grains are perpendicular.

Actually a much greater difference was found and therefore the columnar grain effects cannot be explained solely in terms of the crystal anisotropy. The remainder of this improvement may be a grain size effect. The "effective" grain sizes in a columnar grain casting were determined by measuring the mean distance between grain boundaries in two mutually perpendicular directions. Measuring parallel to the direction of growth, the distance between grain boundaries was found to average 3.0 mm, whereas in the perpendicular direction the mean path was only 0.4 mm. On the basis of these results, it appears that roughly two-thirds the improvement in the magnetic properties of a favorably aligned columnar grain structure may be attributed to the magnetic anisotropy factor, while the remainder is due to the reduction in the number of grains which are intercepted by the internal magnetic path.

Optimum Values: The values obtained in the [100] directions on these alloys are of special interest, since they demonstrate the degree of improvement which can be realized by proper control of the crystallographic variables. Table VIII presents a comparison of the best energy values obtained on the favorably oriented crystals along with the values that are usually quoted for these alloys.

Conclusions

1—Massive crystals of Alnico alloys can be produced either by the slow sintering of fine, non-oxidized powders or by the coarsening of relatively fine-grained castings.

2—The results obtained on single-crystal specimens show that the orientation of the magnetic axis has a marked effect on the performance of Alnico permanent magnets. The squarest demagnetization curves and the highest coercive force and maximum energy values are obtained in the cube direction, while the octagonal direction is the lowest in these respects. With a [100] magnetic axis, the maximum energy of sintered Alnico 5 crystals was about 6,000,000 gauss-oersteds which is appreciably greater than the [111] orientation value of 3,500,000 gauss-oersteds. Cast Alnico 6 crystals under similar circumstances gave values of 6,500,000 and 2,900,000 gauss-oersteds.

3—An analysis of the results obtained on single-crystal and polycrystalline specimens indicates that the maximum energy value is reduced by a refinement in the grain size.

4—Cube textures are developed in castings of these alloys and desired orientations of this texture can be realized by the controlled extraction of the heat of solidification. A cast texture in which the columnar grains are aligned parallel to the magnetic axis will produce significantly higher maximum energies than the normal, randomly oriented, grain structure. These pronounced orientation effects can be explained partially on the basis of a cube texture coupled with the pronounced magnetic anisotropy and partially as the result of a larger effective grain size as measured in the direction of the magnetic axis.

5—A cube oriented, cast Alnico 5 crystal produced an energy value in excess of 7,500,000 gauss-oersteds.

Table VIII. Optimum Energy Values

Alloy	Nominal Value	Best Value
Sintered 5	3,500,000	6,320,000
Cast 6	4,000,000	6,550,000
Cast 5	4,500,000	7,590,000

Acknowledgment

The authors are indebted to the personnel of the General Electric Co. who supported or assisted in these programs over a three-year period. Particularly, we wish to acknowledge the support of Z. Jeffries and E. E. George who authorized certain phases of this work and the assistance of R. J. Studders for his invaluable contributions on the crystal preparation techniques. The many valuable discussions contributed by staff members of the Rensselaer Polytechnic Institute and the General Electric Research Laboratory contributed greatly to the progress of this work.

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Vanadium-Uranium Constitutional Diagram

by H. A. Saller and F. A. Rough

Studies of the V-U system have been made to determine the constitutional diagram. The diagram is fairly simple, since no intermediate phases are formed. Additions of vanadium lower the uranium melting point and allotropic transformation temperatures. The maximum solid solubility of vanadium in uranium is 12 atomic pct and the maximum solid solubility of uranium in vanadium is about 4 atomic pct.

WITH the advent of high purity iodide vanadium,[1] it became of interest to study the alloying characteristics of vanadium and uranium. Alloys were prepared covering the entire system and were studied using a combination of metallographic examination and thermal and X-ray analyses. As a consequence of this work, the V-U constitutional diagram was evolved.

In order to prepare suitable alloys for equilibrium-phase studies, it is desirable to have the purest possible starting materials. For this investigation, calcium-reduced vanadium, de Boer process crystal-bar vanadium, and good Mallinkrodt Chemical Co. uranium were used. The first work was done using the best vanadium then available, that being calcium-reduced vanadium produced at Knolls Atomic Power Laboratory. Subsequently, the important features of the diagram were checked using alloys made with crystal-bar vanadium produced at Battelle. These checks are in agreement with the earlier work.

Analyses of the starting materials are contained in Table I. Only minor amounts of any impurities were present in either the vanadium crystal bar or uranium. Nevertheless, care was exercised in selecting the uranium for the alloys. The procedure followed was to section the stock into suitable pieces for melting, and macroetch each piece. Only those pieces which appeared to be clean by macroetch examination were used for alloying.

Table I. Impurities in the Starting Materials

Element Detected	Uranium, Pct	Iodide Vanadium, Parts per Million
Fe	<0.01	150-250
Ni	<0.01	50
Al	<0.01	20-100
Mo	<0.01	50
Cr	<0.01	Trace
W	—	200
Cu	<0.01	50
V	<0.01	—
Si	<0.01	50-150
P	<0.01	—
Mg	<0.01	50
O_2	—	280-370
H_2	—	6-17
N_2	—	40-60

Experimental Procedure

Melting: Alloys with 0 to 50 atomic pct V were induction melted in beryllia (BeO) crucibles under vacuum of 10 microns pressure or better. A number of remelts was frequently required to insure uniformity of the individual ingots. Although no visible reaction between the alloy and crucible was found in any of these operations, the alloys were checked by spectroscopic analysis. Only trace amounts of beryllium were detected in the alloys.

Alloys containing 50 to 100 atomic pct V were arc melted in a water-cooled copper crucible under an atmosphere of helium. A tungsten electrode was used. Ingots of 10 to 15 g were produced readily by turning and remelting a few times. Such small ingots were necessary because high purity vanadium was not available in appreciable quantities at this time. After melting, the ingots were examined metallographically for segregation and were consolidated by remelting before fabrication was attempted. Spectroscopic analyses showed that only small amounts of tungsten were picked up during the arc-melting process.

Fabrication of Alloys: Alloys containing up to 20 atomic pct V could be fabricated by rolling in air at 600°C with 5 min between passes. After each pass through the rolling mill the alloys were returned to

H. A. SALLER and F. A. ROUGH are Supervisor and Assistant Supervisor, respectively, in metallurgy, Battelle Memorial Institute, Columbus, Ohio.

Discussion on this paper, TP 3402E, may be sent, 2 copies, to AIME by Dec. 1, 1953. Manuscript, June 16, 1952. Cleveland Meeting, October 1953.

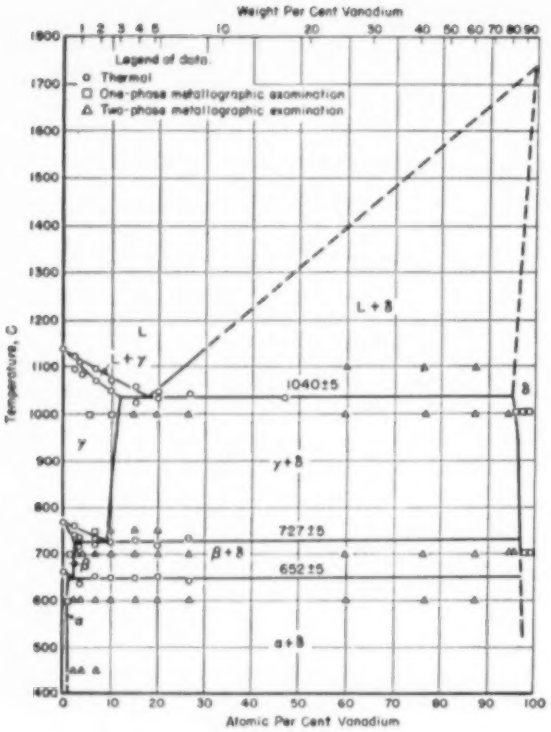

Fig. 1—V-U constitutional diagram.

a furnace that had an atmosphere of argon. The alloys around 20 atomic pct V appeared to be less amenable to this procedure than were the lower alloys, however the fabrication was satisfactory for this work.

High vanadium alloys containing up to 10 atomic pct U were fabricated by jacketing in stainless steel and rolling at 1000°C with 5 min between passes through the rolling mill. No attempts were made to fabricate alloys of intermediate compositions, since preliminary work had shown that two-phase regions extended across the system with no intervening compounds. It is expected that these intermediate two-phase alloys would also be workable, especially if jacketing techniques are used.

Sampling for Chemical Analysis: Samples for chemical analyses were cut from the top and bottom of each of the small induction-melted ingots of high uranium alloys. Since the high vanadium ingots were quite small, sampling techniques in this case were limited. Usually, whole metallographic samples of these alloys were submitted for analysis after thorough examination.

Heat Treating: All heat treating was done under vacuum of one micron pressure or better. The procedure followed was to homogenize the as-rolled alloys by soaking for 40 hr at 1000°C. Subsequent heat treatments at various temperatures were carried out as indicated in a later section of this paper.

Metallography: Specimens were cut using Allison, No. 46A3, cutoff wheels 0.020 in. thick. The samples were then ground wet through the usual rough papers and were finished wet on 240, 400, and 600 grit abrasives.

Alloys with 0 to 30 atomic pct V were polished and etched in a solution of chromic and acetic acids, Table II. Polishing was usually complete after 30 sec to 1 min at 50 v with a current density of approximately 20 amp per sq in. Etching was obtained by dropping the voltage to 6 to 10 v in the same solution. Relief, sometimes troublesome in two-phase alloys, was readily avoided by polishing mechanically with stannic oxide on a wheel covered with billiard cloth. This was followed by etching at 6 to 10 v in the chromic and acetic acid electrolyte. The same etch also served as a macroetch.

High vanadium alloys, 30 to 100 atomic pct V, were prepared for examination by grinding through the same series of abrasive papers, finishing on a billiard cloth with stannic oxide abrasive, and electropolishing for a few seconds at 10 to 20 v. The solution for this operation consisted of sulphuric acid and methyl alcohol. The exact composition is shown in Table II. This polish served to remove scratches and worked metal and also to etch two-phase alloys. Solid-solution-type high vanadium alloys were further etched by swabbing with a solution of hydrofluoric and nitric acids in water, Table

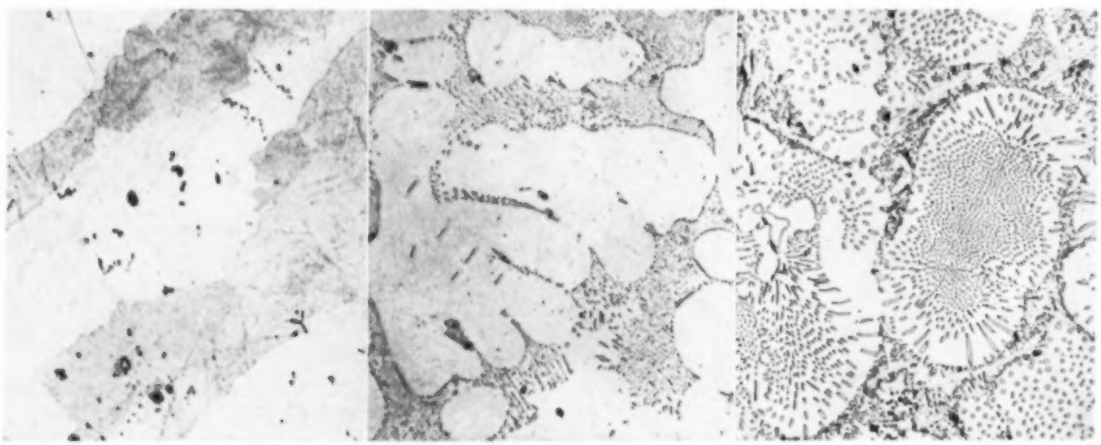

Fig. 2—100 pct U as cast. X100. Fig. 3—7 atomic pct V alloy as cast. X250. Fig. 4—15 atomic pct V alloy as cast. X250.

Figs. 2 to 4—Area reduced approximately 25 pct for reproduction.

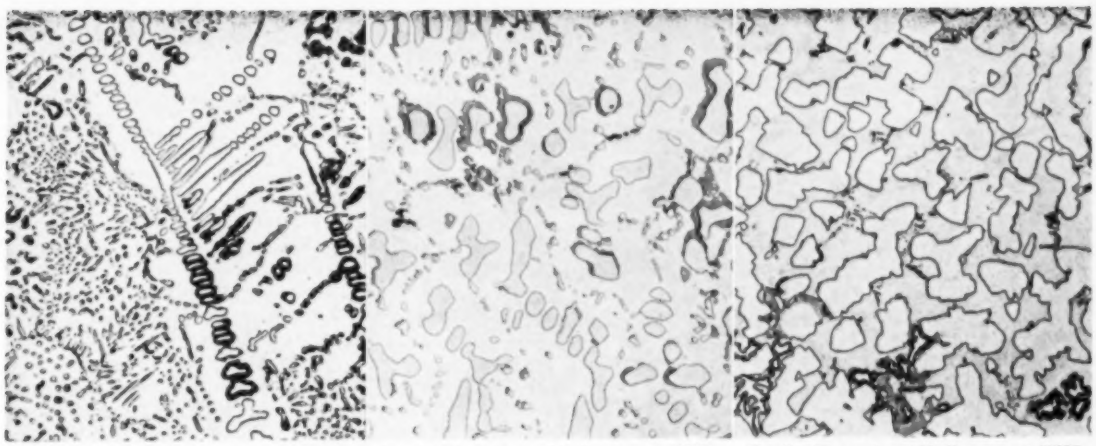

Fig. 5—20 atomic pct V alloy as cast. X250.

Fig. 6—27 atomic pct V alloy as cast. X250.

Fig. 7—47 atomic pct V alloy as cast. X250.

Figs. 5 to 7—Area reduced approximately 25 pct for reproduction.

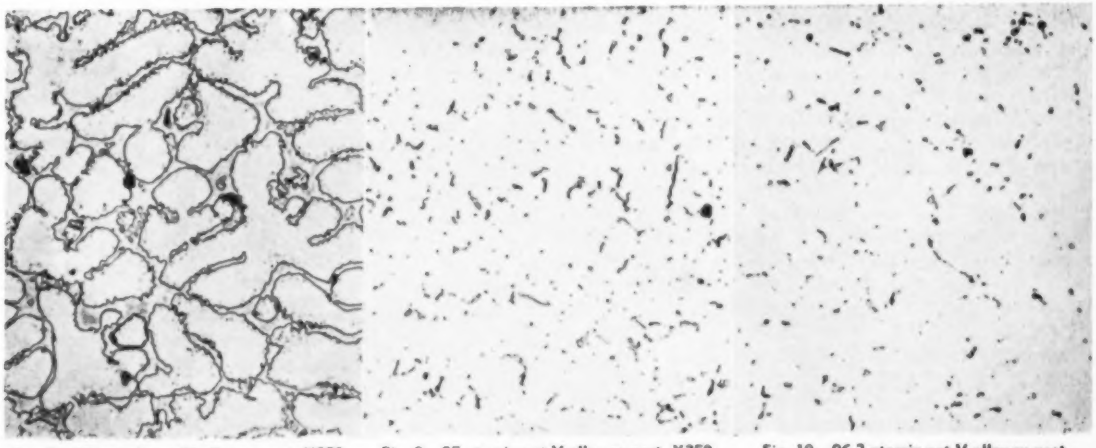

Fig. 8—80 atomic pct V alloy as cast. X250.

Fig. 9—95 atomic pct V alloy as cast. X250.

Fig. 10—96.2 atomic pct V alloy as cast. X250.

Figs. 8 to 10—Area reduced approximately 25 pct for reproduction.

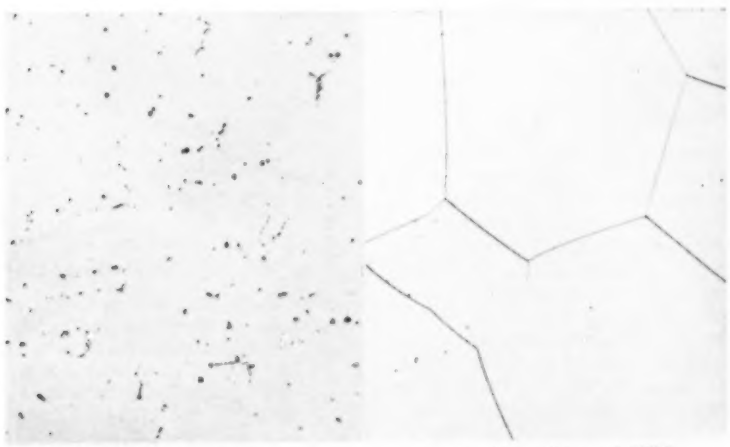

Fig. 11—97.5 atomic pct V alloy as cast. X250.

Fig. 12—100 pct V as cast. X250.

Figs. 11 and 12—Area reduced approximately 25 pct for reproduction.

Table II. Polishing and Etching Solutions

1	Electrolyte for high uranium alloys: 1 part base solution—100 g CrO_3 and 118 ml H_2O 3 parts glacial acetic acid
2	Electrolyte for high vanadium alloys: 20 vol pct concentrated H_2SO_4 80 vol pct methyl alcohol Few drops H_2O
3	Acid etching solution for high vanadium alloys: 1 part concentrated HNO_3 1 part concentrated HF 1 part H_2O

II. This etch brought out grain boundaries which were not visible after the electropolishing operation.

X-Ray Examination: A general survey of the alloy system was not made by X-ray examination. However, a number of confirming checks were made on the results of other studies by making X-ray diffraction patterns from metallographic sample surfaces.

Thermal Analysis: To determine solid-phase transformations, thermal analyses were performed on alloys across the constitutional diagram. Runs were also made for liquidus-solidus data on the high uranium alloys. Standard techniques of analysis were employed for this work using the differential-thermocouple arrangement.[2] The temperature differential between the neutral and active samples was plotted against the temperature of the active sample under test. Solid-phase transformations were then readily detectable in alloys containing appreciable amounts of a high uranium phase. Best results were obtained by cycling through transformation temperatures one or more times. The data obtained by heating appeared to be most reliable and were little affected by variations of heating rates between 1° and 5°C per min. Cooling data are not considered to be reliable, since difficulty was encountered with supercooling.

In all of this solid-phase work, the thermocouple bead was protected from the uranium by refractory insulators. A piece of refractory in the specimen hole prevented contact between the thermocouple bead and specimen, but allowed radiation directly between them. By using a fine wire, 30 gage thermocouple, this arrangement was found to give good sensitivity at the temperatures of testing.

The best data on the liquidus-solidus determinations were obtained by heating once through the melting range. After the first melting, alloys were usually segregated and unusable. During this work, the thermocouples were protected by using small specially prepared BeO protection tubes.

Results

Constitutional Diagram: The V-U constitutional diagram has been established and is shown in Fig. 1. Since no intermediate phases are formed, the diagram is relatively straightforward. It is characterized, generally, by a high temperature eutectic and lowering of the uranium allotropic transitions by additions of vanadium. The eutectic reaction occurs at 1040° ±5°C and 18 atomic pct V. The solubility of vanadium in γ uranium is a maximum of 12 atomic pct at the eutectic, and decreases to 9 atomic pct at the eutectoid temperature of 727° ±5°C, Fig. 1. The β-uranium region is more restricted than the γ field with 2.0 atomic pct V being soluble at 700°C. The α region is restricted still further. In this case, a solubility of less than 1.5 atomic pct V at 600°C was found.

The solid solubility of uranium in vanadium is limited at all temperatures. The solid-solution line is a maximum at the eutectic temperature, Fig. 1. Here the solubility is 4 atomic pct, 15 wt pct, uranium. At lower temperatures somewhat lower solubilities were observed.

Microstructures of Cast Alloys: Many of the general features of the V-U system are apparent from the series of micrographs of as-cast alloys shown in Figs. 2 to 12. The first micrograph of the series, Fig. 2, shows the structure of arc-melted uranium. Addition of 7 atomic pct V alters the uranium structure producing primary uranium islands surrounded by transformed eutectic, Fig. 3. A somewhat similar structure is found in a 15 pct alloy, Fig. 4. However, in this case precipitation has occurred in the primary-uranium islands. In these two structures the eutectic was altered by the γ and β eutectoid transformations.

Primary dendrites of vanadium are present in a 20 atomic pct alloy indicating that it is on the vanadium-rich side of the eutectic composition, Fig. 5. Structures of additional alloys on the vanadium-rich side of the eutectic composition are shown in Figs. 6 and 7. The eutectic in these alloys is not evident as a two-phase structure. This is assumed to be due to precipitation of vanadium on the primary-vanadium particles during the eutectic reaction.

A decreasing or disappearing uranium phase is observed as the vanadium content increases from 80 to 97.5 pct, Figs. 8 to 11. In the 80 pct alloy considerable uranium-rich material is present while in the 95 pct alloy only scattered uranium-rich particles remain to be observed. A scattering of tiny particles of uranium-rich material also appears to be present in the 96.2 and 97.5 atomic pct alloys, Figs. 10 and 11.

Thermal Data: Some of the general features of the diagram have been illustrated by metallographic structures. As much, or perhaps more, data are also observable from a survey of thermal studies, Fig. 1. The eutectic, γ eutectoid, β eutectoid, and even approximate solubilities might be determined from these data alone, although the diagram is the result of combined studies.

Metallographic Studies of Solid Solubilities: The results of metallographic studies are summarized and plotted in Fig. 1. Data are shown for high uranium alloys quenched from temperatures of 1000°, 750°, 700°, 600°, and 450°C, and for high vanadium alloys from 1100°, 1000°, and 700°C.

Alloys for this work were homogenized by holding for 40 hr at 1000°C and quenching. Samples thus treated were held for appropriate times and quenched from the temperatures of interest. In determining the solubilities of vanadium in α uranium and of uranium in vanadium, the alloys were cold worked before heat treatment to accelerate the approach to equilibrium.

Acknowledgment

The work reported in this paper was performed under Contract W-7405-eng-82 for the Atomic Energy Commission.

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[1] J. W. Nash, R. E. Durtschi, I. E. Campbell, and H. R. Ogden: The Preparation and Properties of Iodide Vanadium. Electrochemical Society Meeting, Philadelphia. May 7, 1952.

[2] Nat. Bur. Standards *TP* 170 (1921).

Silver-Cadmium Eutectoid

by G. R. Speich and David J. Mack

The transformation of β was studied by isothermal methods. At all temperatures, the β transforms quickly to fine grained β'' which develops silver-rich striations. At higher temperatures the striations disappear, the final structure being Widmanstatten α in β'. At lower temperatures, the striated β'' is consumed by pearlite nodules of $\alpha + \beta'$ which in turn form the Widmanstatten α in β'. The transformation is unlike any previously reported for a eutectoid.

AS part of a general program of study on the eutectoid reaction, the Ag-Cd eutectoid seemed particularly attractive because the β phase which undergoes the reaction is another of the typical "electron compounds," AgCd, having the disordered body-centered cubic structure. This work deals with the eutectoid which occurs at 50.5 wt pct Ag, and not with the eutectoid which has been reported at 42.9 pct Ag.[1]

There has been no work reported specifically on the Ag-Cd eutectoid which was studied. The only information available on this eutectoid is that work done in the determination of the phase diagram. For the most part, the terminal portions of the diagram, Fig. 1, are well established; however, the region from 40 to 60 pct Cd is still somewhat in doubt. The X-ray evidence[2-4] in this region is in conflict with the results of thermal analysis. X-ray analysis[3] does not show a polymorphic transformation at about 240°C as indicated by thermal analysis.[1, 5] Even the X-ray evidence, within itself, is confusing in this region of the diagram. One investigator[2] reports the β phase as hexagonal close-packed and has found three phases in the one-phase β field. Other X-ray investigators[3, 4] report the β phase as body-centered cubic.

The authors believe that much of the confusion resulted from incomplete homogenization of the alloys. It was found that it takes almost a week to produce a completely homogeneous two-phase structure at 370°C. Another possible source of error is the volatilization of cadmium from the surface and cracks of the specimen during annealing with the possible formation of a cadmium-poor phase.

The only metallographic data available on this eutectoid alloy are those of Durrant[1] and Fraenkel and Wolff.[5] This information is very limited. The phase diagram chosen as most nearly correct is that in the Metals Handbook,[6] which is almost identical with the phase diagram suggested by Durrant.[1]

Materials and Procedure

The alloy was prepared from high purity silver (999.5 plus fine) and high purity cadmium (0.02 Pb, 0.005 Cu, trace Fe). The metals were melted in carbon under a nitrogen atmosphere. Some cadmium was lost by volatilization but by remelting several times and adding cadmium a 200 g ingot of approximately eutectoid composition was obtained. Because the CdO fumes are quite toxic, the exit gas from the furnace was led through a water trap to condense the CdO.

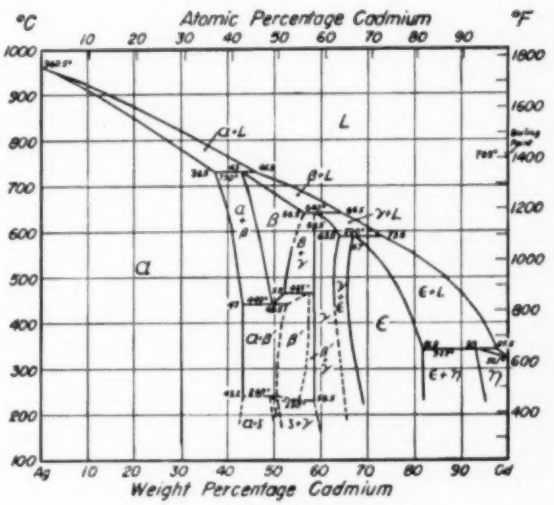

Fig. 1—Ag-Cd phase diagram.[6]

The ingot was homogenized at 650°C for 24 hr, no attempt was made to prevent decadmiumization. This resulted in a narrow decadmiumized rim on the ingot which was removed. Filings for analysis were obtained from cross sections of the ingot. Silver was determined by the Volhard thiocyanate method,[7] cadmium by difference.

The ingot analyzed 50.8 pct Ag at the top of the ingot and 50.7 pct at the middle and at the bottom of the ingot. This alloy was only slightly hypoeutectoid compared to the accepted value of 50.5 pct Ag and was used for the isothermal studies. It was felt that further attempts to adjust the composition might be futile because of the volatility of the cadmium.

The ingot was sectioned to specimens approximately ¾ x ¾ x ⅛ in. These specimens were "austenitized" for 3 hr in air at 650°C to yield homogeneous β and then quenched into a salt bath held at constant subeutectoid temperatures where the transformation

G. R. SPEICH is associated with the Atomic Power Div., Westinghouse Electric Corp., Pittsburgh, and D. J. MACK, Member AIME, is Associate Professor, Dept. of Metallurgical Engineering, University of Wisconsin, Madison, Wisc.

Discussion on this paper, TP 3379E, may be sent, 2 copies, to AIME by Dec. 1, 1953. Manuscript, April 15, 1952. Cleveland Meeting, October 1953.

This paper represents part of a thesis by G. R. Speich submitted in partial fulfillment of requirements for the degree of Master of Science to the Graduate Faculty of the University of Wisconsin.

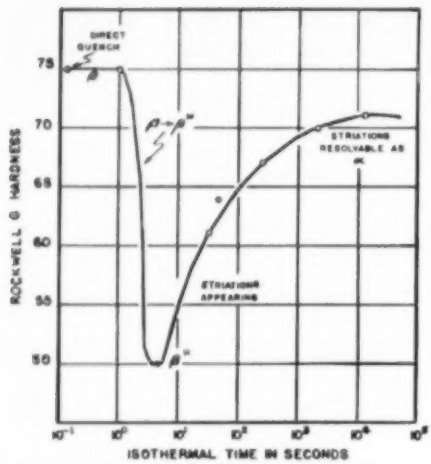

Fig. 2—Hardness of specimens isothermally transformed at 400°C.

was allowed to proceed. Specimens withdrawn from the salt bath were quenched in cold water.

The progress of the transformation was followed by metallographic methods and also by the use of hardness measurements. Specimens were given a preliminary polish on broadcloth using No. 600 alundum, final polishing being on felt using magnesia at slow speed. The only etching reagent that produced satisfactory results was one containing: chromium oxide, 20 g; sodium sulphate, 1.5 g; and water, 100 ml. The etchant was applied by swabbing and gave better results for specimens transformed at lower temperatures when diluted with 5 parts of water.

Experimental Results

The nature of the isothermal transformation of the β phase changes with temperature although the change is gradual from near eutectoid temperatures, 440°C, to the alleged polymorphic transformation at 240°C. There are certain features of the transformation that are common to all temperatures in this range. These are as follows:

1—The β phase transforms sluggishly enough so that it can readily be retained at room temperature. The retained β is very coarse grained and is readily recognized microscopically by its salmon-pink color after etching. This makes the alloy appear pink to the naked eye. Since the β can be easily retained to room temperature,[1] it presumably also exists for a short time in the isothermal bath.

2—The large grained β then rapidly transforms into fine grained β''* which can be recognized by its light yellow color. This change is accomplished by a pronounced drop in hardness, as shown in Fig. 2.

* The following terminology will be used for the various phases formed in this Ag-Cd alloy:
α — terminal solid solution, silver rich, face-centered cubic.
β — high temperature intermediate solid solution, body-centered cubic.
β'' — mestastable transition phase, supposedly hexagonal close-packed.
β' — equilibrium phase, ordered body-centered cubic.
ζ — low temperature, equilibrium phase, hexagonal close-packed.

3—The fine grained β'' develops striations, as illustrated in Fig. 3. The striations seem to start at the grain boundaries and grow completely across the β'' grains. They are straight, parallel, and regularly spaced, usually only one set appearing in a β'' grain. They cause an increase in the hardness of the β'' as shown in Fig. 2. As the transformation temperature decreases, the striations become finer and more profuse as can be seen by comparing Figs. 3 and 8. At lower temperatures there is an increasing tendency for the striations to form along more than one set of crystallographic planes of the β'' giving less regular appearing striations. This is illustrated in Fig. 4. The striations are always associated with the light etching, yellow β''.

4—Coincident with, or shortly after the striations appear in the β'', a rejection of white α begins to take place as indicated in Fig. 5. This rejection decreases in amount with decreasing temperature of transformation and virtually ceases below 350°.

While the sequence of changes just described is common to the isothermal decomposition of β at all temperatures between 440° and 240°C, subsequent changes vary with temperature.

With further holding time in the range from about 440° to 400°C, the striations disappear and the amount of white α increases. This is shown in Fig. 6. At the same time the dark etching purple-pink colored phase, β', appears in the regions where the striations have disappeared. Ultimately the striations and the β'' in which they originally formed disappear completely, the equilibrium structure of α and β' remaining. The equilibrium structure is shown in Fig. 7.

At about 400°C the striated β'' begins to break down by nucleation and growth of pearlitic ($\alpha + \beta'$) nodules, Fig. 8. Not all of the β'' is consumed by these nodules, some of the striations apparently developing the proper composition to form silver-rich α. When this composition is reached, an interface develops and the striations break away from the parent β'', forming flat plates of white α. While this

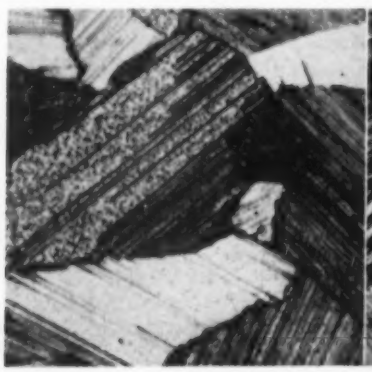

Fig. 3—5 min at 400°C. Striated β'' grains with traces of α at the boundaries. X250.

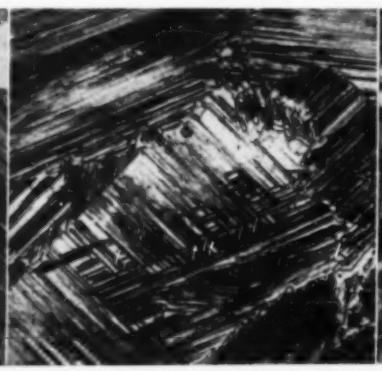

Fig. 4—2 hr at 350°C. Striated β'' with some α at the boundaries. X250.

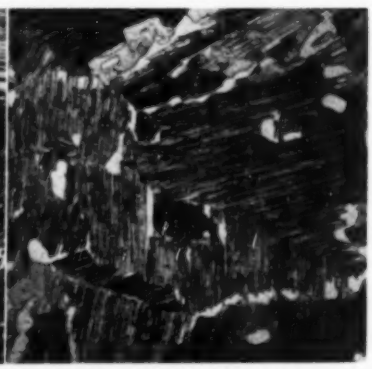

Fig. 5—30 min at 420°C. White α in striated β''. X250.

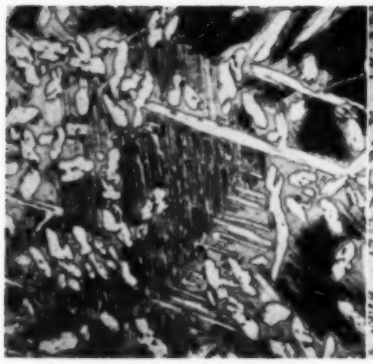

Fig. 6—16 hr at 420°C. α in the form of Widmanstatten precipitate and as rounded particles. Matrix is residual striated β'' plus β'. X250.

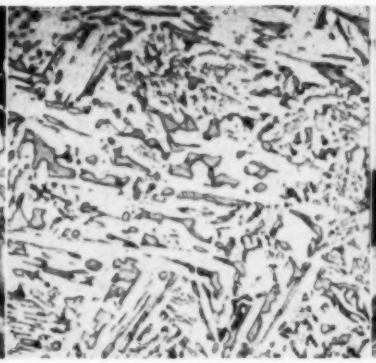

Fig. 7—144 hr at 420°C. Almost all α and β'. Traces of β'' still exist. X250.

Fig. 8—30 min at 370°C. Pearlitic nodules growing in β''. X250.

compositional adjustment is occurring, the remaining β'' is developing the composition of cadmium-rich β'. To complete the transformation, $\beta'' \rightarrow \beta'$, an ordering must also take place. Thus the final equilibrium structure in this temperature range of 400° to 350°C consists of α and β', being similar to Fig. 7. It is interesting to note that no lamellar pearlite is ever found in the structure of this alloy after long holding times at any temperature. This pearlite does not spheroidize. It just gradually disappears, its place being taken by the Widmanstätten distribution of α in β'. When the transformation occurs in the neighborhood of 350°C, there seems to be less tendency for the β'' to transform by the nucleation and growth of pearlitic nodules. Instead, the decomposition of the β'' is by growth of the striations. They become wider, sharper, and better defined and ultimately develop a definite interface with the β'' matrix as shown in Fig. 9. At this point the striations are readily seen to be α. While the striations are developing into α, the β'' matrix is transforming to β' in a very interesting manner. The yellow β'' first changes color to that of the purple β', there being a definite color interface but not a phase interface. This is illustrated in Fig. 10. Then suddenly a discrete phase boundary appears where only the color interface previously existed. Fig. 11 shows α platelets, and the β' growing into the β''. The $\beta'' \rightarrow \beta'$ reaction is only partially completed.

Around 300°C and below, the transformation of the striated β'' takes place entirely by the nucleation and growth of two phase ($\alpha + \beta'$) pearlitic nodules, Fig. 12. The pearlitic nodules consume the striations before they can become discrete α plates; the pearlite in turn giving way to the structure shown in Fig. 7.

It should be kept in mind that the change in the character of the transformation with decreasing tem-

Fig. 9—89 hr at 350°C. Striated β'' with α and β'. X250.

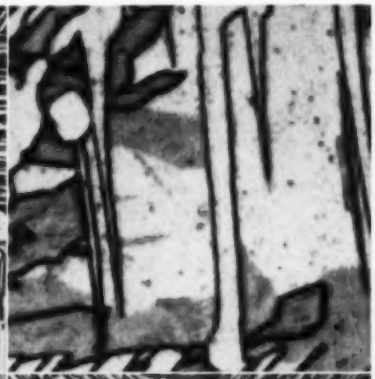

Fig. 10—144 hr at 350°C. β'' transforming to β'. X750.

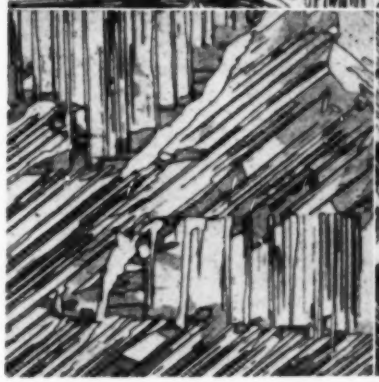

Fig. 11—144 hr at 350°C. α platelets in matrix β''. Some β' has formed. X250.

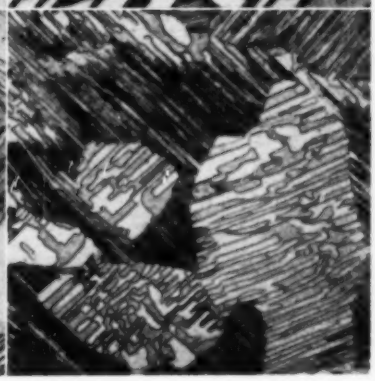

Fig. 12—3 hr at 300°C. Striated β'' with pearlitic ($\alpha + \beta'$) nodules. X1000.

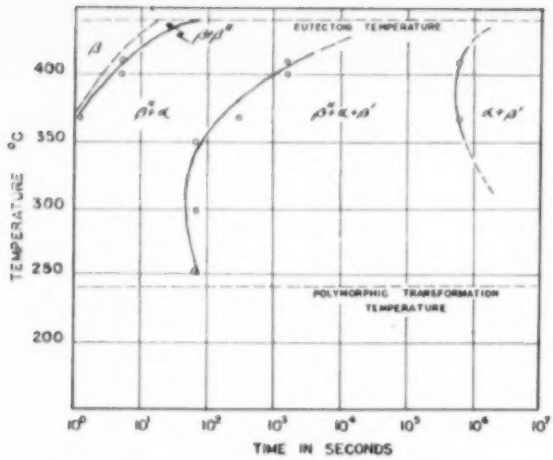

Fig. 13—T-T-T diagram for the Ag-Cd eutectoid alloy.

peratures is gradual, there is no definite temperature where one transformation sequence is suddenly replaced by a different sequence. The time-temperature-transformation characteristics of the β phase for temperatures above 240°C are shown in Fig. 13.

As previously mentioned, the existence of a polymorphic transformation at 240°C is somewhat in doubt. Its existence was not confirmed in this work.

The transformation as just described, continues essentially unchanged down to about 234°C. When the eutectoid specimens are quenched into the isothermal bath below this temperature, only a part of the β quickly transforms into β'', which is striated as formed, Fig. 14. Some thin platelets of α also appear within a few seconds. In about an hour at 200°C, pearlite nodules appear in the β'' as indicated in Fig. 15, and they grow until the β'' is entirely consumed. Once the β'' is consumed, there is no tendency for the growing pearlite nodule to grow into the surrounding β. This is shown in Fig. 16. During this time the α platelets start to spheroidize.

After the β'' has been consumed by the growing pearlite the remaining retained β transforms slowly to striated β'', which in turn transforms to pearlite. While this β'' is transforming to pearlite, the pearlite which had formed previously is disappearing, its place being taken by the coarser Widmanstätten α in the β' and a structure similar to that shown in Fig. 7 is obtained.

The transformation was not followed to lower temperatures because of the very long times required for transformation. The retained β is stable for at least 16 months at room temperature.

Discussion

Any mechanism for the eutectoid decomposition in this alloy must explain:

1—The isothermal formation of a fine grained, yellow etching β'' from a coarse grained, pink etching β.

2—The appearance of striations in the β'', and the parallelism of the striations.

3—The disappearance of the striations with time, and the subsequent appearance of α platelets in a matrix of β'' or of two-phase nodules of α plus β', depending on the temperature of transformation.

4—The transformation of the residual light etching β'' to the dark etching β'.

5—The fact that the β', when first developed, differs in color from the β'', but ultimately develops a sharp boundary with the β''.

6—Why the pearlite nodules formed below 240°C consume only the β'' and do not continue growing into the surrounding β.

7—The continuous disappearance of lamellar pearlite with no evidence of spheroidization and the appearance of the coarser $\alpha + \beta'$ mixture in its place.

The mechanism of this eutectoid decomposition may be as follows: The high temperature, body-centered cubic β phase is retained by quenching into cold water. Some evidence of this is shown by the fact that etch pits on the surface of quenched specimens are cubic. Durrant[1] has also reported that the β phase, when quenched, shows no sign of decomposition. The β phase is also retained at high temperatures for a few seconds in the isothermal bath.

The β phase transforms rapidly by nucleation and growth into the metastable β'' in the temperature range of 440° to 240°C. This transformation explains the drastic change in grain size that the specimens undergo when held for only a few seconds in the latter temperature range. The presence of a metastable phase in the alloys near eutectoid composition has been reported by several investigators.[2, 4] There is however, some disagreement as to the true crystal structure of the metastable phase. It has been reported as hexagonal or rhombohedral[4] and also as ordered body-centered cubic like the β' phase[2]. The authors attempted some X-ray analysis of these structures, but were unable to successfully interpret the patterns obtained. It is not believed that the metastable phase is cubic; the structure of the meta-

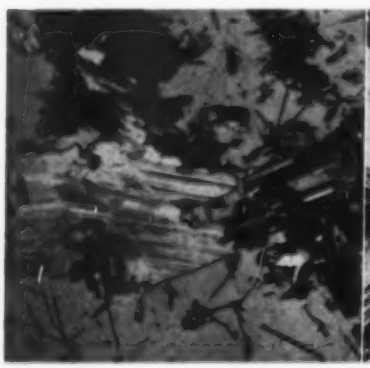

Fig. 14—4 sec at 200°C. Patches of striated β'' in retained β. Some Widmanstatten α. X250.

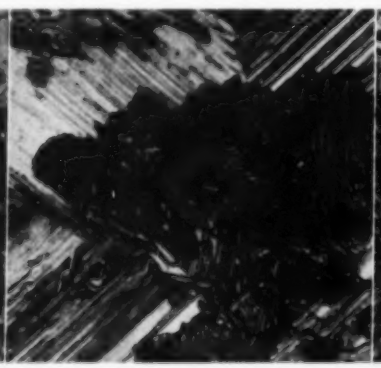

Fig. 15—1 hr at 200°C. Pearlite growing in striated β''. X750.

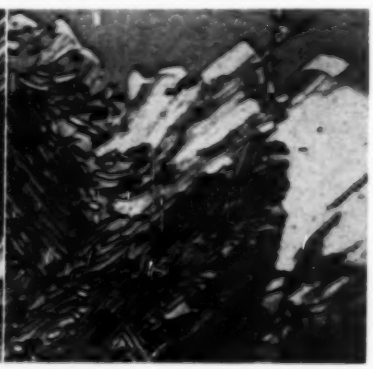

Fig. 16—1 hr at 200°C. Pearlite growing in striated β''. Note α rim which has formed between the β'' and the retained β. X2000.

stable phase is probably hexagonal. This is supported by the fact that etch pits in the β'' were indicative of a hexagonal structure.

The striations which appear in the β'' are probably the result of a "bainite-type" reaction of the type found in steels[8] and certain Cu-Al alloys[9]. The "bainite" mechanism in this alloy may possibly be explained as follows:

1—The silver atoms segregate by diffusion to form regions in the β'' of high silver content surrounded by regions of low silver content. This is the point at which the striations first appear and coincides with the rapid increase in hardness, Fig. 2.

2—The β'' of high silver content usually transforms into α platelets above 300°C. At lower temperatures the striated β'' transforms only into pearlite ($\alpha + \beta'$).

3—Above 350°C the residual β'' matrix then transforms into β'.

It may be asked why the striations should appear on only one set of crystallographic planes of the β''. A possible explanation of this phenomenon is that given by Barrett[10] in his discussion of Widmanstätten precipitates. If it is assumed that the striations are concentration gradients which are formed prior to the precipitation of α, and that the metastable β'' is hexagonal close-packed, then it would be expected that the striations would form on only one set of crystallographic planes of the β''. This is due to the fact that the (111) plane in the α (face-centered cubic) and the basal plane in the β'' (hexagonal close-packed) are planes of closest matching. A precipitate of α on the basal plane of the β'' would therefore be anticipated, since precipitation takes place in such a way that matched planes occur at the matrix-precipitate interface. The striations form on the same planes where the α is going to precipitate. This may explain the formation of α and striations on preferred crystallographic planes. This, however, does not explain the formation, in some cases, of Widmanstätten needles of α on crystallographic planes different from those on which the striations form, Fig. 6, nor the tendency to form more than one set of striations within a single β'' grain at transformation temperatures below 300°.

Above 300°C the striations transform into α platelets. At this and lower temperatures, however, the striations do not form platelets, but are consumed by two phase pearlitic nodules. This means that at about 350°C the surface energy requirement of a platelet cannot be met and therefore it does not form. The pearlite which consumes the striations at these temperatures is in turn replaced by a structure of lower energy, coarse $\alpha + \beta'$.

The consumption of the β'' by the β' is an ordering reaction. The type of reaction suggested in this paper, $\beta \rightarrow \beta'' \rightarrow \beta'$, has also been suggested by Kosolapov and Trapeznikov[4]. The presence of only a color boundary between the β'' and β' probably indicates that the necessary adjustment in chemical composition has been made but coherency still exists between the two phases. As the β'' becomes ordered, coherency is lost and a sharp interphase boundary is formed.

Item 6, given previously, relating to the fact that below 234°C the growing pearlite nodule will consume only the striated β'' and will not continue growing into the surrounding β is a very important observation on the growth of this pearlite. The α rim which forms around the β'', Fig. 16, and which might be considered as a mechanical obstruction to the growth of the pearlite is not the important factor. Areas in the structure can be found where this α rim fails to form and yet the growing pearlite stops at the β''-β interface. This results from inherent differences of the β and β''.

The fact that the lamellar pearlite continuously disappears in favor of a coarser aggregate of α and β' has also been observed in other eutectoid alloys. This phenomenon has an important bearing on the morphology of the pearlites and will be discussed in detail in another paper.

Summary

The isothermal transformation of the Ag-Cd eutectoid alloy has been studied at subeutectoid temperatures. Although certain features of the transformation, i.e., retention of the high temperature β, its subsequent transformation to fine grained β'' and the formation of silver-rich striations in the β'' are common to all temperatures below 440°C, the subsequent features of the transformation change with temperature. At high temperatures the striated structure disappears forming a heavy Widmanstätten pattern of α in β'; around 370°C, the striated β'' begins to decompose by nucleation and growth of pearlite as well as by the formation of α platelets from the striations. Below 300°C the transformation takes place only by means of the pearlite reaction. But at all temperatures, the final result is the same, a coarse structure of α in β'.

The presence of the polymorphic transformation at 240°C was not confirmed by the metallographic methods employed.

Acknowledgment

The authors wish to express their appreciation to R. B. Caples, of Anaconda Copper Mining Co., who donated the cadmium for this study; for the advice of V. W. Meloche, of the Chemistry Department, in regard to the chemical analysis of the alloy; for the financial assistance of the Wisconsin Alumni Research Foundation, under RF50:315, to carry out this investigation; for the aid of R. C. Wiggens in the construction of the experimental apparatus; and for the helpful criticism offered by S. A. Kulin.

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Kinetics of the Oxidation of Galena in Sodium Hydroxide Solutions Under Oxygen Pressure

by J. E. Andersen, J. Halpern, and C. S. Samis

In the presence of oxygen, galena is oxidized in an aqueous medium containing sodium hydroxide, in accordance with the following reaction:

$$PbS + 2O_2 + 3OH^- \rightarrow HPbO_2^- + SO_4^= + H_2O$$

A novel method was devised for following this reaction which takes place in an autoclave under oxygen pressure, by measuring the concentration of $HPbO_2^-$ in the solution with a cathode ray polarograph employing stationary platinum electrodes. Using this procedure a study was made of the kinetics of the reaction, in which the effect of a number of variables, including temperature, oxygen pressure, NaOH concentration, and agitation, on the rate, were determined. The results of this study are described and discussed, in terms of possible mechanisms for the reaction.

IT is known that sulphide minerals can be oxidized in aqueous media in the presence of oxygen under pressure. Reactions of this type can be classified in two categories depending upon whether the products of oxidation are insoluble or soluble in the aqueous medium. An example of the first type of reaction is the oxidation of pyrite in alkaline solutions, giving rise to an insoluble iron oxide. The kinetics of this reaction have been investigated and its mechanism established.[1] It has been applied in the oxidation of iron sulphides present in refractory gold ores to improve the subsequent recovery of gold by cyanidation.[2] The second type of reaction finds application where it is desired to recover the metal by leaching during oxidation. In this case a medium is selected in which the oxidized mineral is soluble. For example, nickel, copper, and cobalt sulphide ores can be treated by oxidation in the presence of a solution of ammonia dissolving the nickel, copper, and cobalt as the metal ammine sulphate salts.[3] A similar treatment has also been reported to apply to zinc sulphide ores.[4]

It is known that lead sulphate is soluble in solutions of sodium hydroxide or ammonium acetate. It should therefore be possible to dissolve the lead from galena ores by aqueous oxidation with oxygen under pressure using either of these solutions. The applicability of the ammonium acetate treatment has been investigated and confirmed in a recent study.[5]

The present paper describes the results of a similar study in which the kinetics of the oxidation of galena in sodium hydroxide solutions have been investigated. The object of this investigation was primarily to obtain information of a fundamental nature relating to the kinetics and mechanism of this reaction.

The use of pulps of comminuted ore in a study of this type is undesirable because of the difficulty in controlling and measuring the surface area. The measurements were therefore made using galena crystals of measured surface area and in this way absolute reaction rates were obtained.

The reaction was found to proceed as follows:

$$PbS + 2O_2 + 3OH^- \rightarrow HPbO_2^- + SO_4^= + H_2O \quad [1]$$

The products are sodium plumbite and sodium sulphate salts which dissolve in the aqueous solution.

The reaction studies were carried out in an autoclave in which a desired pressure of oxygen was maintained. The reaction was followed by measuring the concentration of lead in the solution with a cathode ray polarograph. The results obtained in this investigation are presented and discussed in the present paper.

Experimental

Materials: The crystals of galena were obtained from Violamac Mines, Sandon, B. C. The following impurities were indicated by spectrographic analysis carried out by the Provincial Assay Office, Victoria, B. C.: Sn, 0.02 to 0.2 pct; Sb, 0.07 to 0.7; Zn, 0.01 to 0.1; Si, Fe, Mg, As, less than 0.05 pct; Ag, 126 oz per ton, the latter determined by standard fire-assaying procedure.

After cutting a specimen measuring approximately 5x7x12 mm, the crystal surfaces were ground parallel to the 100 axes using No. 2 emery, washed with water, and the dimensions were measured with a micrometer. Oxygen gas was of commercial grade and supplied in cylinders by Canadian Liquid Air. Solutions were made up with chemicals of chemically pure grade and distilled water.

Equipment: Autoclave: The autoclave used in these studies was constructed of stainless steel and

J. E. ANDERSEN is Graduate Student and Holder of the Cominco Fellowship, J. HALPERN is Assistant Professor of Metallurgy, and C. S. SAMIS is Associate Professor of Metallurgy, Dept. of Mining and Metallurgy, The University of British Columbia, Vancouver, B.C., Canada.

Discussion on this paper, TP 3407D, may be sent, 2 copies, to AIME by June 1, 1953. Manuscript, June 9, 1952; revised, Dec. 1, 1952. Spokane Regional Meeting, May 1952.

is shown schematically in Fig. 1. The inside dimensions were 2 in. diam x 6 in. high. The autoclave was equipped with a thermometer well and an external heating jacket. The contents were stirred with a cylindrical steel rotor, driven by a 2.5 in. Alnico magnet, rotated externally below the autoclave. The speed of rotation could be varied from 80 to 250 rpm. A Bourdon gage was used to measure the pressure.

Polarograph: The cathode ray polarograph used to determine the concentration of lead in the solution, as the reaction proceeded, was essentially similar to that described by Randles,[6] and included a cathode ray oscilloscope to amplify and record the vertical (current) and horizontal (voltage) signals. Additional units included an electronically stabilized

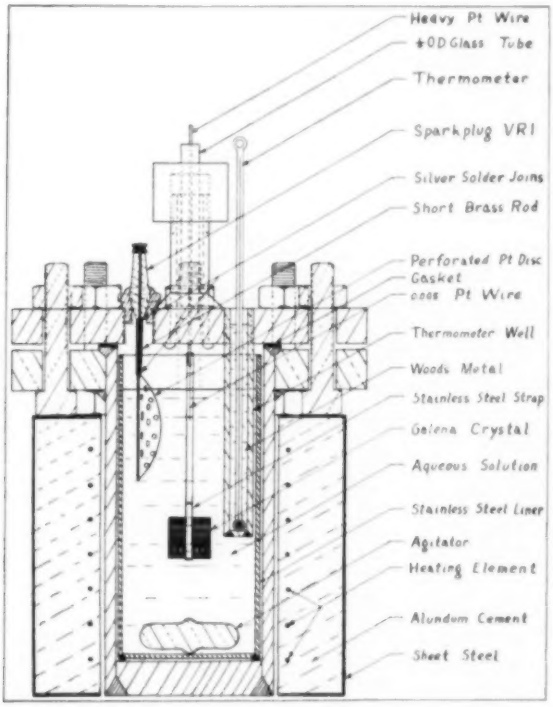

Fig. 1—Schematic drawing showing construction and parts of the autoclave.

voltage supply and a synchronizing unit to control voltage sweep.

The use of a dropping mercury electrode was not feasible under the experimental conditions used (i.e., in an autoclave under pressure) and stationary electrodes were substituted. A small bead of platinum at the end of a 3 mm length of 0.1 mm platinum wire immersed in the solution constituted the polarizable micro electrode (cathode). The unpolarized electrode (anode) was a 2.5 cm disk of perforated platinum foil. Each electrode was connected to an insulated platinum wire which was sealed through the top of the autoclave.

The theory relating to the use of this instrument is given by Randles.[7] A rapid voltage sweep (about 1 v per sec) was used with an interval of 10 to 15 sec between sweeps. A drawing of a typical polarogram is shown in Fig. 2. The height of the lead peak, measured from the level of the preceding oxygen wave, as indicated in the figure, is proportional to the concentration of $HPbO_2^-$ in solution. The validity of this analytical method was confirmed by experimental calibration.

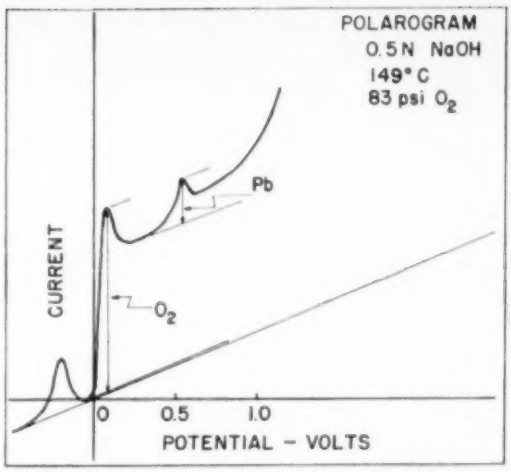

Fig. 2—Drawing of a typical polarogram showing peaks corresponding to oxygen and lead.

Experimental Procedure: 155 milliliters of an aqueous solution of sodium hydroxide of the desired concentration was placed in the autoclave and a crystal of galena, prepared as described earlier, was mounted in a stainless steel holder and suspended below the surface of the solution in the autoclave. The stirrer was turned on and the autoclave heated to a desired temperature. A desired pressure of oxygen was introduced and maintained. Polarograms were obtained at 15 min intervals by photographing the oscillograph screen. At the end of the experiment the concentration of lead in the solution was determined by the ammonium molybdate gravimetric method. This value was used to calibrate the polarographic measurements. Rate curves were plotted, using values for the concentration of lead determined from the polarograms.

Results and Discussion

Reaction Products: Analysis of the solutions indicated that equimolar concentrations of $SO_4^=$ and $HPbO_2^-$ were formed during the reaction. No other forms of lead or sulphur were observed in the solution. The reaction appears to be represented accurately by Eq. 1.

After the reaction, the crystal surface generally showed some etching in the form of lines and pits, apparently formed by intersecting 111 planes. A

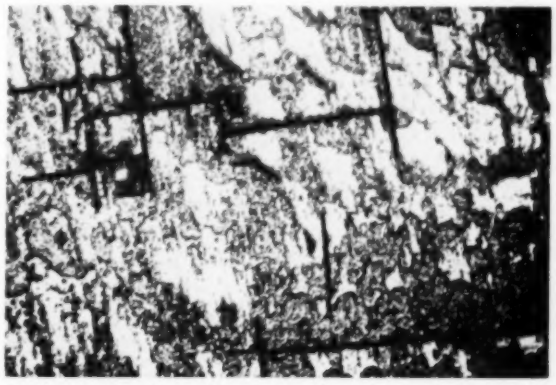

Fig. 3—Micrograph of galena crystal after oxidation in 0.5N NaOH at 150°C for 200 min. X35.

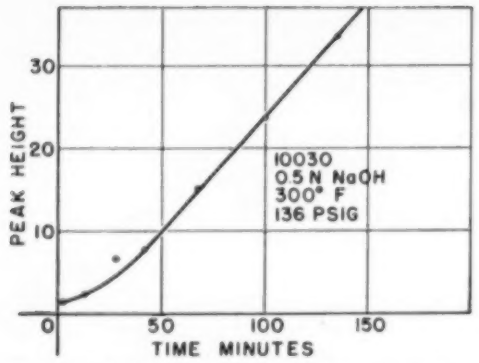

Fig. 4—Typical rate curve for the oxidation of a galena crystal.

micrograph illustrating this effect is shown in Fig. 3. In general there was no evidence of a phase change (formation of solid products) on the galena surface. In a few cases where high NaOH concentrations were used, a loosely adherent yellow coating, believed to be hydrated PbO, was observed to form after cooling.

The Rate Curves: A typical rate curve for the reaction is shown in Fig. 4. An initial induction period was generally present and is believed to be due to the slow dissolution of an oxidized film on the galena surface formed during exposure to air and polishing of the crystal.

Following this induction period, the rate curves were generally linear for the duration of the experiments (60 to 300 min). Reaction rates were calculated from the slopes of these linear plots. It was found that under given experimental conditions, this rate was proportional to the surface area of the galena crystal used. This is shown in Table I. The amount of galena dissolved during any experiment was small, in all cases less than 4 pct of the initial weight of the crystal, so that the apparent surface area remained substantially constant during each experiment. This accounts for the linear reaction rate curves. Reaction rates determined in this way were found to be reproducible to within ±5 pct even when different galena crystals were used.

Effect of Oxygen Partial Pressure: Experiments were made at 123°C in 0.5N NaOH, using different partial pressures of oxygen ranging from 0 to 11 atm. The results are shown in Fig. 5.

It is seen that the rate of oxidation and solution of galena is proportional to the square root of the partial pressure or concentration of oxygen. This indicates that the oxygen participating in the rate controlling step of the reaction is in a dissociated state.

Table I. Rate of Oxidation of Galena in NaOH Solution

NaOH concentration — 0.5 mols per liter
Temperature — 149° C
O_2 partial pressure — 83 psi (5.64 atm)
Stirrer speed — 48 cm per sec

Galena Surface Area, Sq Cm	Dissolution Rate of PbS			
	Mg per Min	Mg per Sq Cm per Min	Mols per Sq Cm per Sec	Deviation, Pct
4.02	0.845	0.210	1.47×10^{-6}	+2.1
4.56	0.935	0.205	1.44×10^{-6}	0
8.71	1.745	0.204	1.42×10^{-6}	+1.4
Mean value		0.206	1.44×10^{-6}	

Effect of Sodium Hydroxide Concentration: The effect of the sodium hydroxide concentration on the kinetics of the reaction was investigated in a series of experiments at 149°C. The concentration of NaOH was varied from 0.5 to 6N. The results are given in Table II and plotted in Fig. 6, using arbitrary units.

It was found that increasing the concentration of NaOH from 0.5 to 6.0N results in a marked lowering of the reaction rate. The shape of the curve is similar to that depicting the change in the square root of the solubility of oxygen with increased NaOH concentration at 25°C, also shown in Fig. 6 and based on data by Geffcken.[5] The similarity of the two relations suggests that the effect of NaOH on the rate can be at least in part accounted for by the decreased solubility of oxygen with increasing NaOH, since it has already been established that the rate is proportional to the square root of the concentration of oxygen.

Effect of Stirring: The effect of the stirrer velocity on the reaction rate is also shown in Table II and

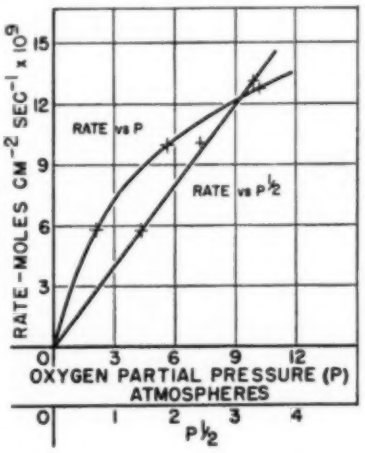

Fig. 5—Effect of the pressure of oxygen on the rate of oxidation of a galena crystal. Solution 0.5N NaOH. Temperature 123°C.

Fig. 6. At low concentrations of NaOH (0.5N) it was found that varying the velocity of the stirrer from 9 to 48 cm per sec had no effect. At higher NaOH concentrations, however, the rate increased markedly with the stirring speed. This effect can be explained in terms of the increase in the viscosity of the medium at higher NaOH concentrations, lowering the rate of diffusion of oxygen to the galena surface. The concentration of oxygen at the reacting surface becomes depleted and the reaction rate is controlled in part by the transport of oxygen to the surface, the rate of which depends on stirring. At low NaOH concentrations the transport of oxygen to the surface is more rapid and the rate of reaction becomes activation controlled and independent of the stirring velocity.

A more quantitative correlation of these effects is impossible in the absence of data relating to the solubility of oxygen and the viscosities of the solutions under the conditions used.

Effect of Temperature: The effect of temperature on the rate of reaction was investigated in the range 93° to 175°C using a 0.5N NaOH solution and an oxygen partial pressure of 5.64 atm. A concentration of 0.5 NaOH was selected for the study of this variable since it has already been demonstrated that under these conditions the reaction rate and therefore the measured activation energy is independent of the stirring velocity.

A good Arrhenius plot was obtained as shown in Fig. 7. The slope corresponds to an apparent activation energy, E, of 6300 cal per mol.

Conclusions

Summary of Kinetic Results: The kinetic results, described above, permit the following conclusions to be drawn regarding the mechanism of the reaction and the nature of the slow or rate controlling stage.

1—The rate controlling step of the reaction is a heterogeneous process occurring at the galena surface and not a homogeneous reaction in solution. This is indicated by the fact that the rate is proportional to the galena surface area.

2—Although four atoms of oxygen are involved in the overall oxidation of one molecule of PbS (Eq. 1), only one atom participates directly in the rate controlling step. This is indicated by the dependence of the rate on the square root of the oxygen pressure.

3—NaOH has only a secondary effect on the kinetics of the reaction, arising from its influence on the solubility and transport of oxygen in the solution. Although OH^- occurs as a reactant in the equation for the overall reaction, it does not appear to participate directly in the rate controlling step, over the range of conditions investigated.

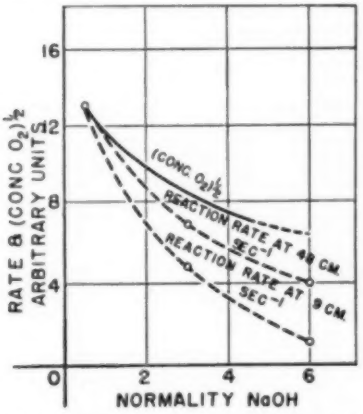

Fig. 6—Effect of the concentration of NaOH on the rate of oxidation of galena and on the solubility of oxygen. Temperature 149°C. O_2 partial pressure 5.64 atm.

4—Water is known to participate in the reaction, since the products are hydrated ions. This reactant cannot be studied as a kinetic variable since its concentration remains effectively constant. However the participation of water in the rate controlling step is indicated by quantitative examination of the kinetic data as shown later.

5—The activation energy for the reaction is 6300 cal per mol.

6—The experimental results show that the transport of oxygen through the solution to the galena surface or the diffusion of reaction products away from the surface do not constitute the rate determining steps under the experimental conditions used, although they may influence the rate at high NaOH concentrations.

7—The rate controlling step of the reaction may involve the oxidation of a lead and sulphur atom simultaneously or alternatively the oxidation of only one of these followed by rapid reaction of the other. Both these possibilities are consistent with the observed fact that the lead and sulphur are always oxidized and dissolved in equimolar concentrations and it is impossible to distinguish between them on the basis of the kinetic measurements.

Proposed Mechanism of the Reaction: A mechanism for the overall reaction involving the following sequence of steps is consistent with all these observations:

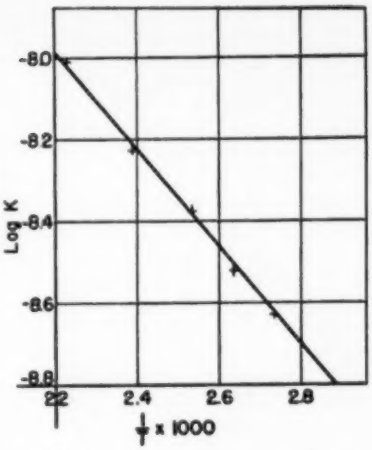

Fig. 7—Arrhenius plot showing the effect of temperature on the rate of oxidation of galena. Solution 0.5N NaOH. O_2 partial pressure 5.64 atm.

Step 1: Solution of gaseous oxygen in the aqueous medium

$$2O_2(g) \overset{\text{Fast}}{\rightleftarrows} 2O_2(aq)$$

Step 2: Adsorption and dissociation of oxygen on the galena surface

$$PbS(s) + \tfrac{1}{2}O_2(aq) \overset{\text{Fast}}{\rightleftarrows} Pb\begin{matrix}/\\ \backslash\end{matrix}\!\!\begin{matrix}O\\ S\end{matrix}(s)$$

Step 3: Hydration of oxygen atom adsorbed on galena site

$$Pb\begin{matrix}/\\ \backslash\end{matrix}\!\!\begin{matrix}O\\ S\end{matrix}(s) + H_2O(l) \xrightarrow{\text{slow}} \left(\begin{matrix}\text{Activated}\\ \text{Complex}\end{matrix}\right)(s) \rightarrow \begin{matrix}OH\\ |\\ Pb\\ |\\ S\end{matrix}\!\!\begin{matrix}OH\\ |\\ |\\ |\end{matrix}(s)$$

Step 4: Formation of reaction products

$$\begin{matrix}OH\\ |\\ Pb\\ |\\ S\end{matrix}\!\!\begin{matrix}OH\\ |\\ |\\ |\end{matrix}(s) + 1\tfrac{1}{2}O_2(aq) + 3OH^-(aq) \overset{\text{Fast}}{\rightarrow} SO_4^{=}(aq) + 2H_2O(l) + HPbO_2^-(aq)$$

Overall reaction:

$$PbS(s) + 2O_2(g) + 3OH^-(aq) \rightarrow SO_4^{=}(aq) + HPbO_2^-(aq) + H_2O(l)$$

The states of the reacting species are represented by the following symbols: (g), the gaseous state; (l), the liquid state; (s), the solid surface state; and (aq), the aqueous solution.

In the above sequence, steps 1 and 2, the solution of oxygen and its chemisorption on galena sites are assumed to be reversible, the equilibrium in each case being rapidly established. The fraction of

Table II. Effect of NaOH Concentration and Stirrer Velocity on the Rate of Oxidation of Galena

Temperature — 149°C
O_2 partial pressure — 5.64 atm

Stirrer Velocity Relative to PbS Surface	NaOH Concentration	Rate Constant (K) Mols Cm^{-2} $Atm^{-1/2}$ Sec^{-1}
9 cm sec^{-1}	0.5N	6.17×10^{-9}
	3 N	2.44×10^{-9}
	6 N	0.53×10^{-9}
48 cm sec^{-1}	0.5N	6.17×10^{-9}
	3 N	3.47×10^{-9}
	6 N	2.01×10^{-9}

galena sites covered with oxygen is small. Step 3 is the slow stage, determining the rate of reaction. The activated complex is formed through the reaction of water with a galena site on which an oxygen atom is adsorbed. The further oxidation of this complex and the formation of the observed products by reaction with OH^- (step 4) then follow rapidly.

The Eyring theory of absolute reaction rates[9] expresses the rate of a chemical reaction as follows:

$$\text{Rate} = \frac{kT}{h} C_1 C_2 \frac{\gamma_1 \gamma_2}{\gamma^\ddagger} \exp\left[\frac{-\Delta F^\ddagger}{RT}\right] \quad [2]$$

where k is the Boltzmann constant; h, Planck's constant; C_1 and C_2 are the concentrations of the reactants; γ_1 and γ_2, the corresponding activity coefficients; $\gamma^\ddagger$ is the activity coefficient of the activated complex; and $\Delta F^\ddagger$, the free energy of activation.

Application of this equation to the rate controlling step (step 3) in the above sequence gives the following expression for the specific rate constant per unit area of galena surface. As a first approximation the activity coefficients have been assumed to be equal to unity.

$$\text{Rate} = \frac{d(\text{PbS})}{dt} = \frac{kT}{h} C_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}} \; C_{H_2O(l)} \exp\left[\frac{-\Delta F^\ddagger}{RT}\right] \quad [3]$$

where (PbS) is the number of mols of PbS reacted in time, t; $\Delta F^\ddagger$, the free energy of activation ($= F^\ddagger - F_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}} - F_{H_2O(l)}$); $C_{H_2O(l)}$, the concentration of liquid water; and $C_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}}$, the concentration of oxygen atoms chemisorbed onto galena surface sites.

The concentration term, $C_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}}$, can be obtained in the following form by thermodynamic consideration of the equilibria involved in steps 1 and 2:

$$C_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}} = C_{PbS(s)} C^{1/2}{}_{O_2(g)} \exp\left[\frac{-\frac{1}{2}(\Delta F_1 + \Delta F_2)}{RT}\right] \quad [4]$$

where $C_{PbS(s)}$ and $C^{1/2}{}_{O_2(g)}$ are the concentrations of galena surface sites and of gaseous oxygen molecules, respectively; ΔF_1 is the standard molar free energy of solution of gaseous oxygen in the aqueous solution, i.e., of step 1 ($= F_{O_2(aq)} - F_{O_2(g)}$); and ΔF_2, the standard molar free energy of adsorption of dissolved oxygen on galena, i.e., of step 2 ($= 2F_{\underset{\text{Pb–S(s)}}{\overset{\text{O}}{\wedge}}} - 2F_{PbS(s)} - F_{O_2(aq)}$).

Combining Eqs. 3 and 4 gives the following expression for the specific reaction rate:

$$\text{Rate} = \frac{kT}{h} C_{PbS(s)} C^{1/2}{}_{O_2(g)} C_{H_2O(l)} \exp\left[\frac{-(\frac{1}{2}\Delta F_1 + \frac{1}{2}\Delta F_2 + \Delta F^\ddagger)}{RT}\right] = \quad [5]$$

$$\frac{kT}{h} C_{PbS(s)} C^{1/2}{}_{O_2(g)} C_{H_2O(l)} \exp\left[\frac{-(F^\ddagger - F_{H_2O(l)} - \frac{1}{2}F_{O_2(g)} - F_{PbS(s)})}{RT}\right] = \quad [6]$$

$$\frac{kT}{h} C_{PbS(s)} C^{1/2}{}_{O_2(g)} C_{H_2O(l)} \exp\left[\frac{(S^\ddagger - S_{H_2O(l)} - \frac{1}{2}S_{O_2(g)} - S_{PbS(s)})}{R}\right] \exp\left[\frac{-(H^\ddagger - H_{H_2O(l)} - \frac{1}{2}H_{O_2(g)} - H_{PbS(s)})}{RT}\right] \quad [7]$$

since $F = H - TS$

where S, H and F are the standard entropies, enthalpies, and free energies of the denoted species.

Eq. 7 can be further expressed in terms of the experimental activation energy, E, as follows:[9]

$$\text{Rate} = e^2 \frac{kT}{h} C_{PbS(s)} C^{1/2}{}_{O_2(g)} C_{H_2O(l)} \exp\left[\frac{S^\ddagger - S_{H_2O(l)} - \frac{1}{2}S_{O_2(g)} - S_{PbS(s)}}{R}\right] \exp\left[\frac{-E}{RT}\right] \quad [8]$$

Assuming the entropies of the solid surface states (i.e., $S^\ddagger$ and $S_{PbS(s)}$) to be equal to zero (since these correspond to vibrational degrees of freedom only, their values will be negligible in comparison with the other terms) and evaluating the remaining terms in Eq. 8 by standard procedures, the rate of reaction at 123°C is calculated to be

$$6.5 \times 10^{-9} \text{ mols cm}^{-2} \text{ atm}^{-1/2} \text{ sec}^{-1}$$

The experimentally observed rate under these conditions is

$$4.2 \times 10^{-9} \text{ mols cm}^{-2} \text{ atm}^{-1/2} \text{ sec}^{-1}$$

This agreement between the observed and calculated values of the rate is considered very good in view of the approximations involved in the calculations and lends further support to the general mechanism which has been proposed, in which the rate controlling step is the reaction of a water molecule with a galena surface site on which an oxygen atom is adsorbed.

Acknowledgment

This work was supported by a Research Grant and a Fellowship from the Consolidated Mining and Smelting Co. of Canada, Ltd.

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Formation of Deformation Bands In Al-3 Pct Mg Monocrystals During Cold Rolling

by J. Herenguel, P. Lacombe, and P. Lelong

IN previous studies on the effect of orientation on the rate of anodic oxidation of Al-3 pct Mg monocrystals of high purity, certain anomalies were observed on the cold-worked metal. These anomalies were shown to correspond to regions of changed orientation within the grains resulting from plastic deformation.[1] In fact, they are deformation bands revealed by differences in rate of oxidation and produced by more or less continuous bending of the lattice about a [111] axis common to the original crystal and the band.[2, 3] Preliminary observations made after relatively large degrees of cold working revealed an approximate twin relationship between the bands and the surrounding crystal. Fig. 1 shows the etch figures formed on such a band and on the original monocrystal after a 67 pct rolling reduction. It is evidently not a true twinning, since there is a broad transition zone between the two systems, however the two extreme orientations are nearly in a twin relationship.

It was decided to investigate these preliminary observations by progressive rolling-reductions on monocrystals of varied initial orientation. From these studies, which form the subject of the present article, it became apparent that the initial observation of an approximate twin relation between the bands and the monocrystal was simply a special case.

Our experiments show that deformation in rolling proceeds by a mechanism analogous to those which have already been observed in the simpler cases of tension and compression. Micrography—in particular, the formation of etch figures—has been applied to the quantitative study of these orientations. In addition, observations have been made of slip lines, of thin oxide films yielding interference colors, of thick films in polarized light, and of etchants giving "engraving." These micrographic methods for studying orientation have established the orientation relationship without any ambiguity, whereas X-ray methods would have given only a statistical result because we were often dealing with thin bands (2 to 100 microns) and even narrower connecting zones covering a maximum of 20 microns.

J. HERENGUEL is Director of Research and P. LELONG is Metallurgist, Centre de Recherches of the Trefileries et Laminoirs du Havre Society, Antony, Seine, France, and P. LACOMBE is Professor at the Ecole des Mines, Paris, France.

Discussion on this paper, TP 3451E, may be sent, 2 copies, to AIME by June 1, 1953. Manuscript, July 23, 1952.

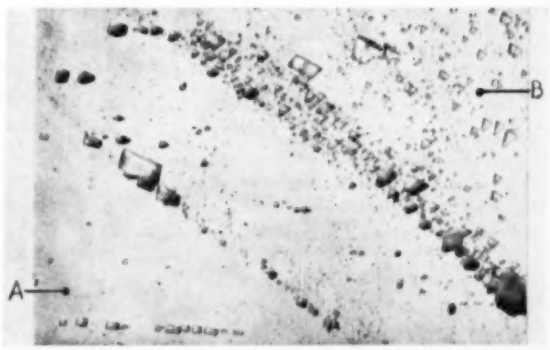

Fig. 1—Al-3 pct Mg monocrystal cold rolled 67 pct and etched for etch-figures. The two extreme portions A and B, in near-twin relation, are connected by a zone of transition pits. X600. Area reduced approximately 50 pct for reproduction.

Specimen Preparation and Methods

The Al-3 pct Mg alloy was prepared from 99.95 pct Al and is of the type used industrially in France for brilliant anodized finishes under the name of Brillalumag. This material combines the normal commercial properties with an enduring brilliance due to the protection of a thick, but perfectly transparent, film of alumina.[4]

The monocrystals were prepared by the method of critical deformation followed by prolonged annealing. Great care was taken to insure perfect homogeneity of composition, to eliminate included crystals,[6, 7] and to avoid the formation of undulations during oxidation.[5] The critical deformation for this alloy is about 1.2 pct (l-l_0/l_0x100) and the subsequent annealing was for one week at 500°C after gradual increase of temperature (35°C per hr). The crystals thus prepared had a section of 10x5 mm and a length of 20 to 40 mm. Each of these crystals was polished electrolytically and etched for the formation of etch-figures with the classical reagent.[8] The orientation was then calculated from their angles, as measured with a goniometer microscope.

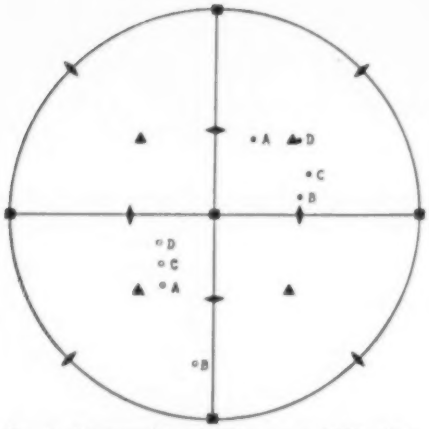

Fig. 2—Stereographic projection on a (100) plane showing the poles of the plane and direction of rolling for crystals A, B, C, and D. Solid circle, pole of the rolling plane. Open circle, pole of the rolling direction.

Rolling was done with cylindrical rolls of 100 mm diam which were degreased before each operation with trichloroethylene. The roll gap was closed progressively and observations were made after each stage. The specimens were always introduced in the rolling mill by the same end and the cold work required was obtained by several passes.

For microexamination, the specimens were polished mechanically and finished electrolytically. They were then etched for the formation of etch-figures with the reagent maintained at an optimum temperature of 7° to 8°C. For observations on thin oxide films, anodic oxidation was carried out under conditions already published.[5] For thick films, oxidation was effected in sulphuric acid (10 pct by volume) at a current density of 1 amp per sq dm for 30 min at 20°C. Etching for "engraving" was produced by the action of the electrolytic-polishing mixture of phosphoric-sulphuric acids at 60° to 70°C without applied current;[6] or alternatively by 20 pct caustic soda at 40° to 50°C. Such etching gives a surface appearance which depends on orientation and can be profitably examined in polarized light.

Experimental Results

Several crystals were cold-rolled. The results on each will be described at successive stages of reduction.

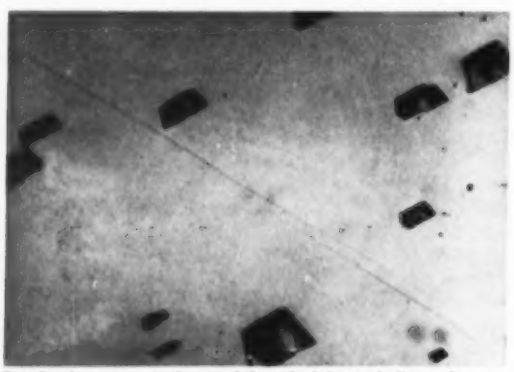

Fig. 3—Appearance of crystal A etched for etch-figure formation after 10 pct reduction. Note the lines which cross the micrograph diagonally. X1000. Area reduced approximately 50 pct for reproduction.

Crystal A: The orientation with respect to the plane and direction of rolling is shown in Fig. 2 which also gives that of the other crystals. The following phenomena were observed as a function of cold working.

1—Rolling Reduction 5 to 10 Pct: Slip lines were visible on the surface of the specimen. After electrolytic polishing of the rolled surface, no local regions of changed orientation were found by any of the different micrographic methods. However, after 10 pct reduction, there appeared certain lines different in character from the classical slip lines. They reappeared even after several successive polishings (removing 0.02 to 0.03 mm of metal) and became more pronounced after etching for the formation of etch-figures, Fig. 3. In addition, they were parallel to the trace of a (111) plane—a plane which later plays an important role.

2—Rolling Reduction 18 Pct: The lines seen after 10 pct reduction disappeared completely but deformation bands began to appear. None of them completely traversed the width or thickness of the specimen, and they were visible on only one of the two rolled surfaces after the different etching treatments.

These bands may be defined in the following manner: the orientation relationship between them and

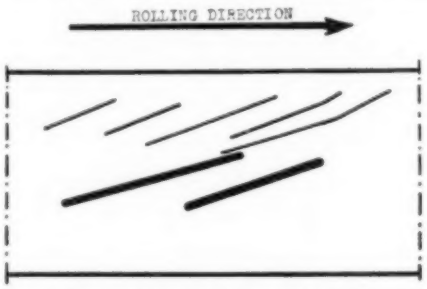

Fig. 4—True position of deformation bands of crystal A as seen in the rolled surface after 18 pct reduction. Sketch magnified approximately 3 times.

the surrounding crystal corresponds to a rotation of 5° to 7° around a [111] axis, which lies almost in the rolling plane and makes a large angle with the rolling direction. The interface between band and crystal was parallel to a (110) plane of the actual crystal, this having been established by observations on two perpendicular faces—the rolled surface and the lengthwise surface. This (110) plane contains the [111] axis of rotation which makes the initial crystal pass from its orientation to that of the bands. In the present case, this (110) plane was slightly inclined to the rolling plane. Figs. 4 and 5 illustrate these observations.

The bands had a thickness covering the range of 5 to 75 microns but were often 30 microns thick. The connecting zones spread over 1 to 2 microns rendering their analysis impossible at this stage of rolling.

3—Rolling Reduction 25 Pct: Increased change, corresponding to rotations up to 10°, and a slight broadening of the transition zones were observed. However, no new bands appeared.

4—Rolling Reduction 45 Pct: The original system of bands continued to change and other systems appeared.

Within the original bands, further local changes of orientation occurred by a mechanism identical

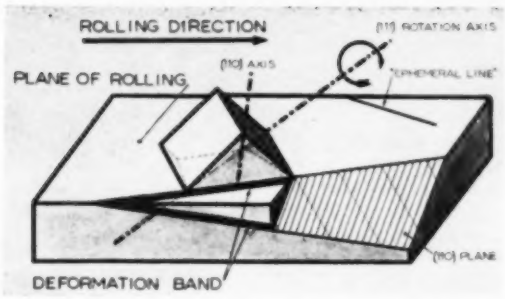

Fig. 5—Diagram showing how the cube representing the crystal lattice in its initial position is oriented with respect to the plane and direction of rolling. Note the conspicuous position of the (110) interface plane and of the [111] axis of rotation. "Ephemeral line" is that observed after 10 pct reduction but which later disappears.

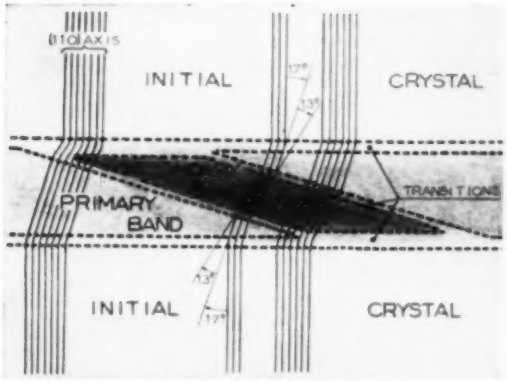

Fig. 6—Diagram showing the formation of a primary band and of a secondary band by double curvature about a [111] axis normal to the paper, becoming localized on a (110) plane.

with that which functioned initially; that is, by rotation about a [111] axis which is therefore common to the original crystal in its present position, to the primary band, and to the secondary band which it contains.

The rotation was 17° between the initial crystal and its primary bands, and 13° between the primary bands and their secondary bands. The total rotation between secondary bands and the initial crystal was thus $13° + 17° = 30°$.

The interface between primary and secondary bands is the (110) plane of the primary band lattice which still contains the [111] axis of rotation. Thus in the diagram of Fig. 6, the plane of the paper is the (111) plane perpendicular to the [111] axis of rotation. The [110] axes which are in fact curved in the connecting zones by the mechanism of band formation are also shown. Fig. 7, taken in polarized light, shows the actual appearance of the surface after "engraving."

The connecting zones between the primary bands and initial crystal now became wider and reached about 6 microns. At high magnifications, these zones were seen to be finely striated in saw-tooth form, of the order of one micron, Fig. 8.

New systems appeared, though on a scale much smaller than the previous ones, but this time covering the whole of the specimen. It was possible to distinguish:

a—Certain systems close to the primary bands and between them. These consisted of thin lamellae (10 microns) of slightly differing orientation (2° to 3°) and regularly alternating. Their interfaces were still straight but it was not possible to identify their direction in relation to the lattices, nor the mode of rotation. Fig. 9 shows such complex systems after "engraving," as seen in polarized light. The fine striations on the primary and secondary bands may be noted also, while Fig. 10 shows this effect in greater detail.

b—In the portions of the crystal which, until now, were free of bands, another system developed made up of alternating lamellae about 10 microns thick and differing slightly in orientation. The general direction of the interfaces was still a (110) plane of the actual crystal, but it was no longer the same one as before, Fig. 11.

Examination of the slip lines on the surface of the polished specimens before the last rolling operation confirmed particularly clearly the existence of the bands and of gradual curvature in the connecting zones. Fig. 12 shows one of these first bands with the secondary bands. At a higher magnification the curvatures appear still more clearly and it will be noted on Fig. 13 that the connecting zone is wider on the upper front than on the other. The secondary bands also appear.

All these descriptions are naturally somewhat schematic. In reality, the initial crystal undergoes a change of orientation as a whole which varies slightly from one point to another and which cannot be explained by the geometry of deformation alone. Fig. 14 is a stereographic projection on a (100) plane of the poles of the rolling plane and

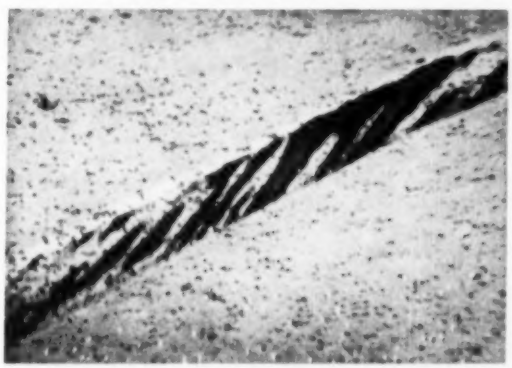

Fig. 7—Appearance of a primary band broken up by secondary bands. The surface was examined in polarized light after etching for engraving. X75. Area reduced approximately 50 pct for reproduction.

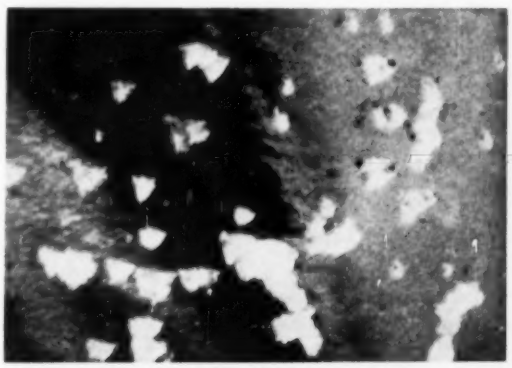

Fig. 8—Saw-tooth striations from the transition zone. Etch pits combined with "engraving." Examination in polarized light. X600. Area reduced approximately 50 pct for reproduction.

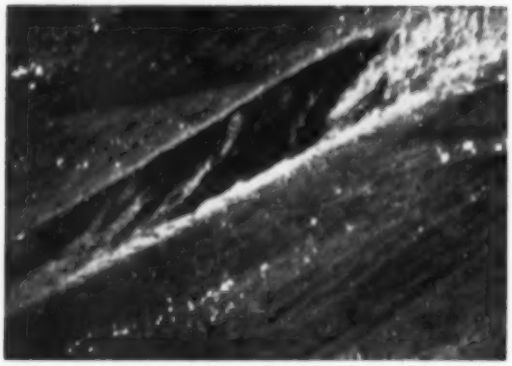

Fig. 9—Complex systems of fine bands in the neighborhood of a large band. Same preparation and examination as in Fig. 7. X75. Area reduced approximately 50 pct for reproduction.

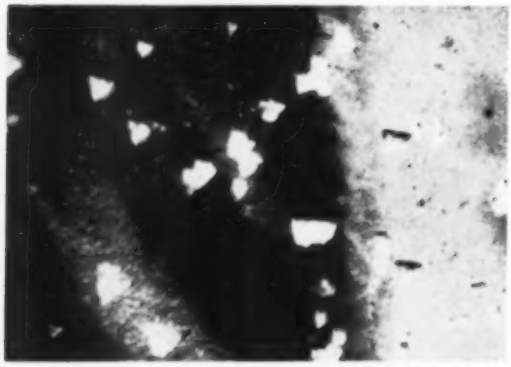

Fig. 10—Fine striations of the primary and secondary bands. See Fig. 7. X600. Area reduced approximately 50 pct for reproduction.

rolling direction after different degrees of cold working for a zone of the crystal judged to be typical of the average behavior.

5—Rolling Reduction 65 Pct: Successive polishing operations made the initial bands disappear. These were approaching nearer to the rolling plane. The complex systems are to be found close by but interpretation is still not possible.

In contrast, far away from these, the system already described, which possesses a (110) plane of the initial crystal as an interface, was still present.

Up to 65 pct reduction, it is striking that the rolled monocrystal was very far from being entirely affected by the bands described. Indeed, they only penetrated up to one fifth of the specimen thickness and from only one surface, in the case of the larger bands, while the finer systems penetrated from one surface only from one third to one half the thickness. This is evidently due to the very great heterogeneity of forces in rolling. These forces applied to the lattice vary through the thickness of the specimen and are very different at each rolling surface.

6—Rolling Reduction 208 Pct: Close to the previously formed large bands, interpretation remains impossible. There were at least two systems which could not be related to the orientation of the initial crystal with any certainty. On the whole of the opposite face, the face on which no system had been previously observed, there now appeared one made up of lamellae 15 microns thick. Interpretation was not possible however.

Far from the initial bands, the system already described was found again but it had not progressed toward the interior. Thus both faces were now covered with fine bands and with several entangled systems. Between these two zones, at the center of the specimen, was a zone which, having undergone only rotation as a whole and simple slipping, was not fragmented.

Crystal B: This crystal was chosen to have an orientation close to that of crystal *A*, see Fig. 2.

Up to 5 pct reduction, nothing was noticed. After 13 pct reduction, bands appeared again with an interface corresponding to a (110) plane of the initial crystal, but this time making a large angle with the rolling plane, in contrast to the case of crystal *A*. The orientation difference was small but increased with increasing rolling reduction. After 20 pct reduction, a rotation of about 12° had occurred about the [111] axis contained by the (110) interface plane. The connecting zone was about 20 microns wide at this stage and the bands 70 microns thick. Analogy with the first-formed bands of crystal *A* is therefore very satisfactory. The presence of distinct bands mixed up with previously formed ones is worth noting. These are much more numerous on the other face of the specimen. This second system was more complex. Its interface, appearing on the large surface, was built up of straight portions, parallel to the trace of a (110) plane but connected by curved portions. On the other hand, the interface was linear on the side surface and still parallel to the same (110) plane. It therefore seems that the interfaces are (110) planes or ruled surfaces and

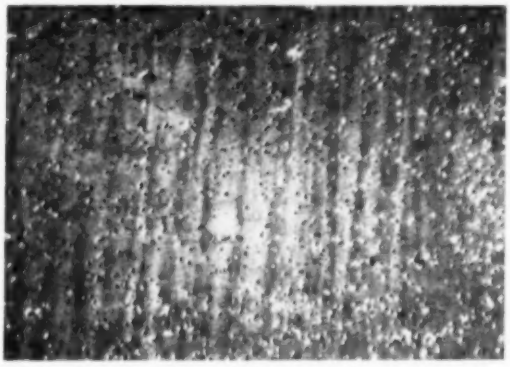

Fig. 11—Systems of bands in alternating lamellae in a portion of the crystal free of large bands. See Fig. 7. X75. Area reduced approximately 50 pct for reproduction.

show a certain analogy with cross slip. The width of the bands was 50 to 60 microns, the connecting zones were spread over about 20 microns, and rotation occurred around the same [111] axis as before, contained in the (110) interface plane (different from that of the system on the other face).

This crystal presented certain marked analogies with crystal *A*. The mechanism by which the bands formed was identical.

Crystal C: The orientation of crystal *C* is given in Fig. 2. After 5 pct reduction, nothing was observed and there was still nothing on the large faces after 15 pct reduction. However on the side surfaces of the crystal, a system of fine bands 20 microns thick was visible. These alternated regularly forming a layer approximately parallel to the rolling plane. This layer was made up of bands of differing orientation. The orientation of the portion of the crystal free of bands, was present also in the disturbed regions where it formed one element of the pattern. However, there was a slight rotation which

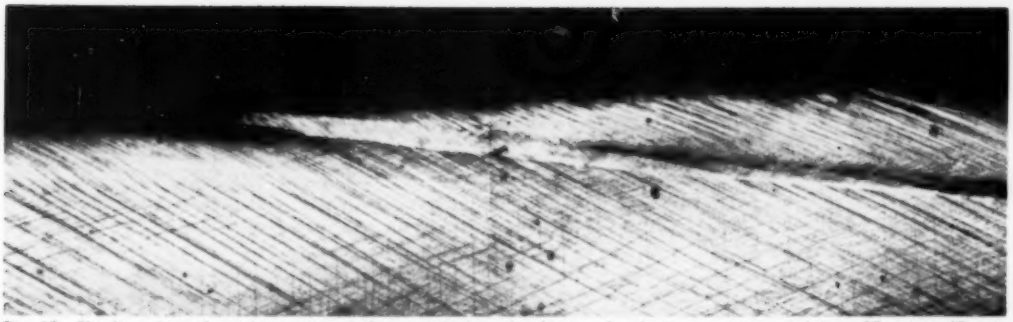

Fig. 12—Slip lines formed on the section of the crystal when the degree of reduction was increased from 25 pct to 45 pct. The primary and secondary deformation bands are revealed by the curvature of the slip lines and by relief on the metal surface. X75. Area reduced approximately 60 pct for reproduction.

made crystallographic identification of the interfaces very uncertain.

In the whole system, three principal orientations were established: one close to that of the surrounding crystal, and two others of slightly differing orientation.

In searching for orientation relationships between neighbors, these seem to be related by rotations of

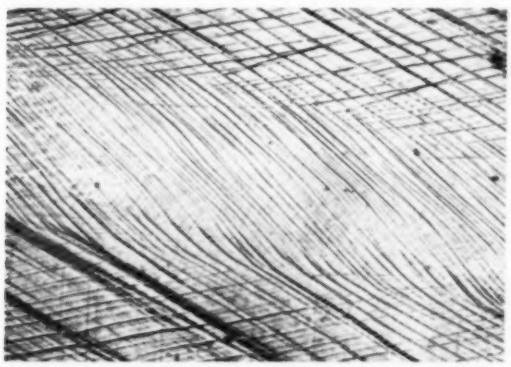

Fig. 13—Portion of Fig. 12 at X600. Note the continuous curvature in the connecting zone and substructure of the band. Area reduced approximately 50 pct for reproduction.

about 5° to 10° around the axes [112], [110], and [100]. These axes cannot be determined with precision however. In like manner, it is not possible to see if the general direction of the interface between the bands themselves is a simple crystallographic plane of the original crystal.

The rotation around a [112] axis has already been observed by Chen and Mathewson[10] by X-ray examination on aluminum monocrystals cold-worked by extension. The interface of the deformation bands was a (110) plane as it is for the rolled crystals *A* and *B* described in this paper.

Crystal D: Crystal *D* was chosen to have a (111) plane almost parallel to the plane of rolling.

1—After 8 Pct Reduction: The etch-figures did not undergo any orientation change but they grouped together in wide zones of high density (20 to 250 microns). The interfaces of these zones appeared to be well defined and, in the plane of rolling, were parallel to the sides of the etch-figures (equilateral triangles almost).

On the rolled surface, thin oxide films and "engraving" revealed deformation bands once more. The orientation of these could not be deduced from angle measurement of the etch-figures. The interfaces were also confirmed.

On the side surfaces, no trace of deformation was revealed by any of the micrographic methods.

2—After 15 Pct Reduction: The intensely attacked regions became more complex. They were to be found in the form of entangled bands formed by two crossing systems.

By measuring a large number of the etch-figures and plotting the orientations on a stereogram, it was found that they were grouped in two principal orientations. One was close to that of the original crystal and the other appeared to be related by a rotation about a common [110] axis. In fact, the great complexity made orientation determination very uncertain.

Discussion and Summary

From the preceding experiments, it may be concluded that when a monocrystal is subjected to progressive rolling-reductions, not only is a general change of orientation produced, but also deformation bands become increasingly numerous and complicated. Such bands, at least those formed during progressive rolling, do not involve the whole thickness of the specimen at the beginning. In certain cases, they form either on only one face in contact with the rolls and then on the other; on both faces at the same time; or they may appear in the interior of the monocrystal. These peculiarities probably arise from variations in the resulting forces and from the orientation of these forces with respect to the induced lattice.

The first two specimens described were most suited

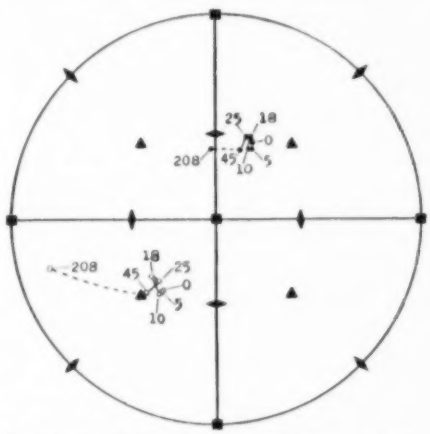

Fig. 14—Positions of the plane and direction of rolling after different degrees of reduction. Stereographic projection on a (100) plane. Solid circle, pole of the rolling plane. Open circle, pole of the rolling direction.

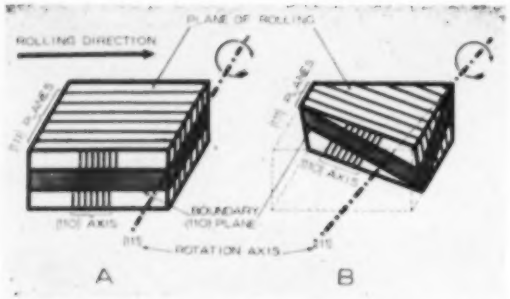

Fig. 15—Bending in crystal A. A—Idealized bending of a lattice oriented with a [111] axis in the plane of rolling and perpendicular to the rolling direction. A (110) plane is thus parallel to the plane of rolling. B—Actual bending which occurred in the case of crystal A.

to precise analysis, as the bands formed initially were few in number, and were relatively large and well separated. In addition, the difference in orientation between bands and crystals was considerable. These bands are formed by progressive curvature of the lattice due to rotation around a [111] axis (the start of the curvature is restricted to a (110) interface plane which contains this [111] axis). The deformation band is thus contained between two parallel planes (110) of the original crystal. For the two specimens of closely similar orientation with respect to rolling, it is the same [111] axis which functions as the axis of rotation. This axis is differentiated from others of the same index [111] because it is that which is most nearly parallel to the rolling plane and perpendicular to the rolling direction. In other words, it corresponds to those {111} planes most nearly perpendicular to the rolling plane and parallel to the direction of rolling. This will be easily appreciated since, under the mechanical conditions of rolling, such {111} planes are literally blocked and prevented from undergoing normal slip.

There is here a fairly close analogy with the mechanism of kinking in hexagonal crystals which occurs when the active direction is parallel to the only slip plane possible. Fig. 15A shows the manner in which bending of the lattice is produced according to this mechanism. Fig. 15B shows the actual arrangement in the case of the first specimen. It is worth pointing out that bending occurs in the only way which permits a shortening of the [110] axes, that is to say, a decrease in thickness of the specimen. In Chen and Mathewson's experiments,[10] the glide direction was in the plane of the tension axis just as it is in the plane of the compression axis in our own experiments.

In the second specimen, bending is no longer given by the curvature of the [110] axis which is the most nearly vertical, but instead by the two other axes almost equally inclined with respect to the rolling plane. Interpretation of the band formation appears more complicated if only the geometric process is considered.

Within the bands themselves, the same mechanism of orientation change in localized regions operates. The rotation occurs about the [11̄1] axis contained by the (110) interface plane of the new lattice. This [111] axis is common to the initial crystal, and the primary and secondary bands. Therefore the orientation changes are simply additive.

In the first stages of deformation it appears clear that certain planes and axes play a somewhat special role which can be expressed in two ways: 1—Crystallographically—it can be said that the {110} planes are planes of high dislocation density, the dislocations being propagated on the {111} planes in the directions [110]. 2—Mechanically—this amounts to recognizing the directions [110] as having minimum elastic resistance to elongation or to shortening.

The formation of the present deformation bands is comparable from the point of view of crystallography with that observed by Cahn[11] and Honeycombe[12] in the tensile extension of aluminum single crystals.

Multiple and complex systems of deformation bands appear as deformation continues, or for certain initial crystal orientations. Only some of these systems have been defined as exactly as the bands already described. It seems they can only be distinguished from them by their more numerous and finer distribution, the rotation axis excepted.

For other systems of thin multiple-lamellae, when the deformation is over a certain limit, it is not possible to identify their positions even relative to one another, with any certainty. Their multiplicity must, without any doubt, finally define the crystallographic properties of rolling textures. It is striking to observe the formation of multiple, superposed patterns, each of them being formed by lamellae of alternating orientation. It is very evident that for texture studies, X-rays can produce only supplementary information, the interpretation of which would appear very difficult in the light of the complex phenomena which have been described for the simpler cases.

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Statistical Grain Structure Studies: Plane Distribution Curves of Regular Polyhedrons

by F. C. Hull and W. J. Houk

To clarify interpretations of grain structures and to assist in calculations of spatial grain size distributions, plane distribution curves have been determined for random sections through four regular polyhedrons approximating the shapes of metal grains. The characteristics of the distribution curve for the average metal grain are predicted.

IT was realized early in the history of metallurgy that metals are polycrystalline aggregates and that the size and shape of crystals affects the properties of the material. Réaumur[1] in 1722 employed the microscope to examine the fractured surfaces of steel and of white and gray cast iron and suggested a polyhedral arrangement of the crystals. The first extensive investigation of the form of crystal grains was carried out by Desch.[2] He examined the disintegrated grains from a β brass sample and noted that the number of faces per grain ranged from eleven to twenty and that the number of edges per face varied from three to eight and the maximum occurred at five.

While it has been found practical to examine isolated grains only in exceptional cases, it is always possible to make a plane section through the metal and examine the shape of the grain sections on the plane of polish. Desch[2] tried to determine the relation between the form of a polyhedron and that of its plane sections for comparison with distribution curves of numbers of sides per grain section of actual metal samples. The polyhedrons investigated were the rhombic and pentagonal dodecahedrons and the orthic tetrakaidecahedron. However, the frequency distributions of the number of sides of plane intersections were not sufficiently characteristic to decide which polyhedron most closely approximated the average grain in a metal.

Determination of Statistical Shape of Grain in Space

Scheil[3] was interested in the problem of calculating the distribution of grain sizes in space from the easily measured distribution of grain section sizes on the plane of polish. Assuming that the grains were spheres and using the plane distribution curve for a sphere shown in Fig. 1, he employed a successive subtraction method to calculate the spatial distribution.

In order to evaluate the accuracy of these calculations, Scheil and Wurst[4] determined the actual distribution of grain sizes in space in their sample of ingot iron by polishing off successive layers and following every individual grain in a series of micrographs. From curves of mean radius of intersection of a given grain vs thickness of metal removed in polishing, Scheil and Wurst attempted to derive the statistical shape of a grain in space. Their calculated plane distribution curve for this shape is compared with the distribution curve for a sphere in Fig. 1. A table of values based on this curve was prepared for calculating spatial distributions of grains. The calculated and measured spatial distributions of their sample then agreed much better than when a spherical shape had been assumed.

In the present paper, an attempt has been made to learn something about the average metal grain by studying in detail the effect of the shape of regular polyhedrons on the plane distribution of areas and shapes of areas produced by random sections through them. From the data presented below, it can be concluded that the plane distribution curve for the average metal grain differs in three fundamental respects from the curve derived by Scheil and Wurst.

Polyhedrons Selected for Study

The polyhedrons selected for the statistical study are illustrated in Fig. 2 and consisted of a cube, a figure formed by cutting off the corners of a cube at the midpoints of the original edges, a tetrakaidecahedron, and a pentagonal dodecahedron. The length of edge on any one figure is a constant. For the above models the edge lengths were 3.50, 4.00, 2.00, and 2.08 in., respectively.

A cube was selected for one of the polyhedrons because of its simple geometry, because it is a form that by repetition can completely fill space, and because it represents a convenient degree of departure from compactness beyond which the shape of

F. C. HULL, Member AIME, is Manager, Metallurgical Section and W. J. HOUK is Research Engineer, Research Laboratories, Westinghouse Electric Corp., East Pittsburgh, Pa.

Discussion on this paper, TP 3499E, may be sent, 2 copies, to AIME by June 1, 1953. Manuscript, Sept. 15, 1952; revision, Jan. 7, 1953. Los Angeles Meeting, February 1953.

A portion of the work described herein was part of a thesis by F. C. Hull submitted in partial fulfillment of requirements for the degree of Doctor of Science at Carnegie Institute of Technology, June 1941.

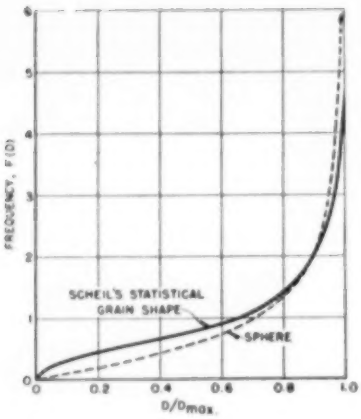


Fig. 1 (left)—Comparison of plane distribution curves of section diameters for a sphere and Scheil's statistical grain shape.

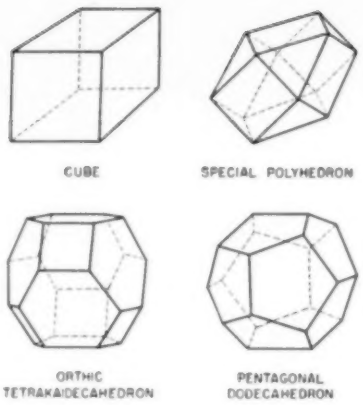


Fig. 2 (right)—Polyhedrons selected for study of plane distributions of area and shapes of sections.

equiaxed metal grains would not be expected to extend. The "special polyhedron," with six square faces and eight triangular faces, represents an arbitrary step in the direction of greater compactness. It is not a space-filling polyhedron.

The tetrakaidecahedron of minimum area, which has eight six-sided faces with double curvature and six four-sided plane faces, is the only polyhedron that satisfies all surface-tension requirements. For ease in constructing the model and evaluating the areas of intersections, this shape has been approximated by the orthic tetrakaidecahedron. Although the form with plane faces and straight edges does not fulfill the surface-tension requirements, the difference in the figures, insofar as the plane distribution curve is concerned, is negligible.

The pentagonal dodecahedron is not in itself a space-filling figure, as is the tetrakaidecahedron. With its twelve five-sided faces, this figure approaches the characteristics of the average metal grain closer than does any other regular polyhedron. However, this comparison is only an approximation because a metal grain has variety in size, shape, and number of faces. By considering the characteristics of all the polyhedrons, some generalizations can be drawn that are applicable to the average metal grain.

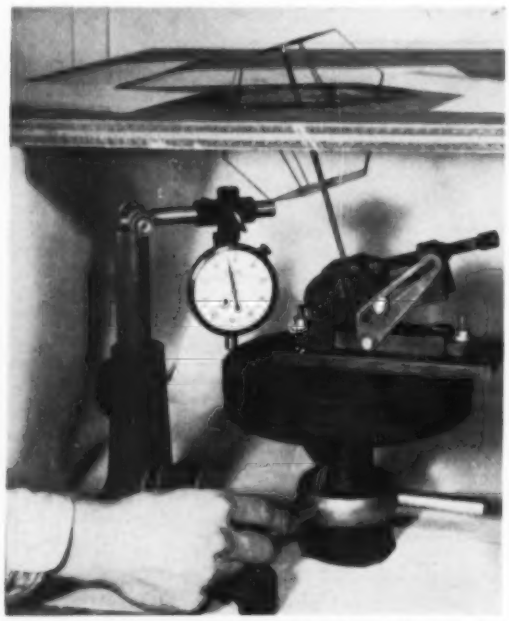


Fig. 3—Position of pentagonal dodecahedron being adjusted with elevating screw.

Experimental Procedure

Preliminary calculations and measurements of plane distribution curves of a cube and the "special polyhedron" were carried out by one of the authors at Carnegie Institute of Technology in 1940.[6] The experimental procedure involved lowering wire models into water, using fifteen different orientations, and measuring the area of intersection as a function of depth of immersion. More recently at the Westinghouse Research Laboratories, the analysis was extended to the tetrakaidecahedron and the pentagonal dodecahedron and to a re-evaluation of the cube, using a more accurate and convenient procedure which was suggested by Roy L. Anderson. The technique is illustrated in Fig. 3.

A wire model of the polyhedron mounted on a rod was held in a tilting bench vise supported by an elevating table borrowed from a Rockwell hardness tester. Vertical displacements of the table and model were read on a dial gage. As the model was raised, it passed through a circular opening in a plywood panel. The top of the panel was parallel to the surface of the elevating table. The shapes and sizes of sections were obtained by sliding templates made of cardboard into contact with each face of the polyhedron intersected by the plane of the panel. The templates were temporarily held in place with masking tape. The panel was then transferred to a desk, a smooth-topped circular blank replaced in the opening, and the area of intersection evaluated with a planimeter.

As the model was raised, the shapes of the intersections were noted. Every time a corner passed the plane of the panel, the intersection polygon gained or lost a side. The elevation was then measured, and the number of sides was counted. From the point of first reaching the panel level, area measurements were made at 0.2-in. intervals up to and including an elevation corresponding to the center of the polyhedron. Because of the symmetry of the figure it was not necessary to go beyond the midpoint. A typical curve of area of intersection and number of sides of the intersection vs elevation, for the tetrakaidecahedron, is shown in Fig. 4.

The procedure used in selecting orientations of the sectioning plane with respect to the polyhedrons was as follows: The polyhedron, for example the cube, was assumed to lie in the center of a stereographic projection reference sphere with a face

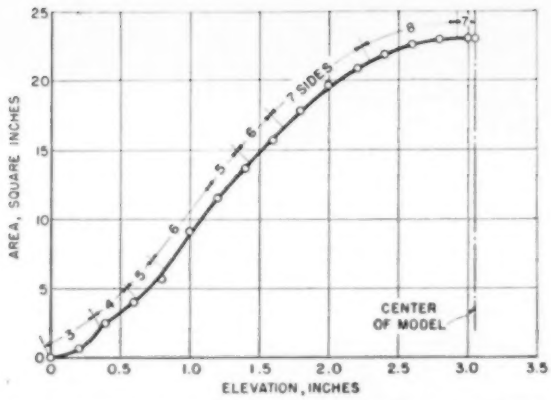


Fig. 4—Area and shape of intersection vs elevation for tetrakaidecahedron of orientation No. 26.

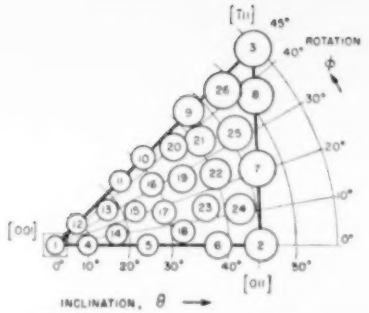


Fig. 5—Polar stereographic plot of orientations of sectioning plane with respect to cube.

parallel to the projection plane. All possible orientations of a plane with respect to the cube (identified by a normal to the plane passing through the center of the cube) can be represented by a point on the reference sphere and the corresponding point on the stereographic projection. However, because of the symmetry of the cube, it is only necessary to consider orientations lying within one of the twenty-four equivalent stereographic triangles defined by poles of the (001), (011), and ($\bar{1}$11) planes. The orientations of the sectioning plane with respect to the cube are illustrated in the polar stereographic net plot in Fig. 5 and were selected to give as complete and representative sampling as possible with only twenty-six points. As an aid to distributing the orientations uniformly over the surface of the reference sphere, circles were drawn around each point with a diameter equivalent to a 5° solid angle. The distortion resulting from the method of plotting leads to a much smaller circle for the [001] direction, for example, than at [$\bar{1}\bar{1}$1]. Angular relationships are listed in Table I for the cube and the other polyhedrons. θ represents angular inclination of the normal to the sectioning plane with respect to the [001] direction and ϕ represents angular rotation about [001]. If an orientation lies on an element of symmetry, it must be weighted as less than one in accordance with the number of equivalent stereographic triangles shared by the orientation. This consideration accounts for the weight factors listed in Table I.

Analysis of the Data

The data obtained by curves of the type illustrated in Fig. 4 have been analyzed to provide curves of frequency of occurrence of intersections with a given number of sides, distribution of areas resulting from intersections with certain numbers of sides, distribution curves of areas, and distribution curves of section diameters. Assume that a polyhedron is cut by a plane of a given orientation and that the area of intersection is A. A parallel plane displaced a distance Δx from the first will have

Table I. Orientations of Normal to Intersecting Plane for Various Polyhedrons

Position No.	Cube (C.I.T.) and Special Polyhedron			Cube			Orthic Tetrakaidecahedron			Pentagonal Dodecahedron		
	θ	ϕ	Weight	θ	ϕ	Weight	θ	ϕ	Weight	θ	ϕ	Weight
1	0°	0°	1/8	0°	0°	1/8	0°	0°	1/6	0°	0°	1/10
2	12	24	1	45	0	1/4	10	0	1/2	8	0	1/2
3	22	45	1/2	54.7	45	1/6	21	0	1/2	13	0	1/2
4	18	14	1	9	0	1/2	29	0	1/2	23	0	1/2
5	35	45	1/2	24	0	1/2	35	0	1/2	27.7	0	1/4
6	31	29	1	38	0	1/2	54.7	0	1/8	5	36	1/2
7	27	10	1	46	21	1/2	46	13	1/2	14	36	1/2
8	45	43	1/2	51	37	1/2	42	21	1/2	23	36	1/2
9	40	31	1	42	45	1/2	39	30	1/2	31	36	1/2
10	38	16	1	31	45	1/2	36	43	1/2	38.5	36	1/6
11	37	0	1/2	24	45	1/2	36	53	1/2	30	11	1/2
12	54.7	45	1/6	8	45	1/2	32	60	1/2	31	30	1
13	50	33	1/2	17	35	1	26	60	1/2	29	21	1
14	47	20	1/2	17	10	1	19	60	1/2	27	4	1
15	45.5	7	1/2	23	23	1	12	60	1/2	26	14	1
16				28	37	1	7	38	1	45	26	1
17				29	17	1	13	35	1	22	18	1
18				32	6	1	15	12	1	19	6	1
19				35	28	1	20	20	1	19	29	1
20				37	40	1	20	39	1	16	18	1
21				41	36	1	25	47	1	11	11	1
22				40	24	1	26	34	1			
23				37	14	1	26	24	1			
24				42	11	1	26	10	1			
25				46	31	1	31	16	1			
26				48	43	1	32	28	1			
27							31	38	1			
28							31	48	1			
29							36	33	1			
30							37	22	1			
31							36	10	1			
32							40	4	1			
33							40	13	1			
34							44	8	1			
35							48	4	1			

θ is the inclination of the normal to the [001] direction.
ϕ is the rotation of the normal around the [001] direction starting from the [010] direction.

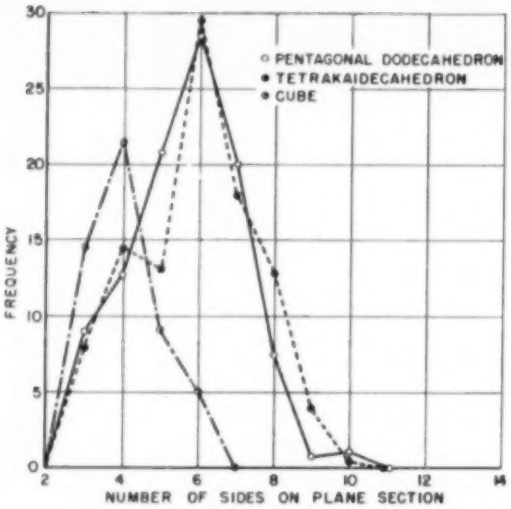


Fig. 6—Distribution of number of sides on plane sections of three polyhedrons.

an area of intersection of $A + \Delta A$. The probability of getting an intersection of area A to $A + \Delta A$ from the given orientation is proportional to Δx. If this probability is summed for all possible orientations and positions of the plane with respect to the polyhedron capable of producing such an area, a frequency distribution of areas is obtained. Orientations lying on an element of symmetry receive less weight, as has been explained.

The frequency function, $F(A)$, has the characteristic that the area under the curve between any two values of area is proportional to the number of intersections per unit area in that size range. In the present paper the "diameter" of an intersection has been defined as $D = \sqrt{A}$. Since it is frequently useful to express distribution functions in terms of diameters, the following relationship is defined:

$$F(A)\Delta A = F(D)\Delta D$$

Since

$$\Delta A = 2D\Delta D$$

then

$$F(D) = 2F(A)\sqrt{A}$$

Discussion of the Distribution Curves

The distributions of number of sides on intersections of the cube, tetrakaidecahedron, and pentagonal dodecahedron are shown in Fig. 6. These curves were obtained by summing the weighted values of Δx, irrespective of areas of the intersection, for each number of sides of the plane section. The cube has a maximum of four-sided sections, with no intersection having more than six sides. In spite of the considerable difference in shape between the other two polyhedrons, both exhibit a pronounced maximum at six sides per plane section, and show surprising similarity over the whole range of the frequency plot. The shapes of these curves are more reasonable than those obtained by Desch's more approximate sampling technique.[7] From the cube with only six faces to the other twelve and fourteen-faced figures, there is a shift to larger numbers of sides on the plane sections, as would be expected.

When the geometry of a polyhedron is considered, it is readily seen that the area of an intersection generally increases with the number of sides of the section. It is difficult, however, to visualize the frequencies and ranges of areas possible for each number of sides of a section. A quantitative presentation of the distribution of areas for each shape of intersection possible is made for the cube, the tetrakaidecahedron, and the pentagonal dodecahedron in Figs. 7 to 9.

For the cube (Fig. 7), small three-sided intersections are very frequent, but the number decreases to zero at 10.4 sq in. Four-sided intersections are found from the smallest up to the largest area. The maximum in the distribution function at 12 to 13 sq in. results from the large number of positions of the sectioning plane that produce the same area when the plane is approximately parallel to a cube face. Five and six-sided intersections have reasonably normal frequency distributions of areas. The maximum area is the same as for the four-sided intersections, but the minimum and average areas increase with number of sides.

The tetrakaidecahedron curves in Fig. 8 exhibit similar trends but extended to intersections with up to ten sides. Although the minimum and average areas increase with the number of sides, the largest section possible has only eight sides. The double maximum in the frequency for six sides is comparable to the curve for four-sided intersections of a cube. It results from the shape and symmetry of the

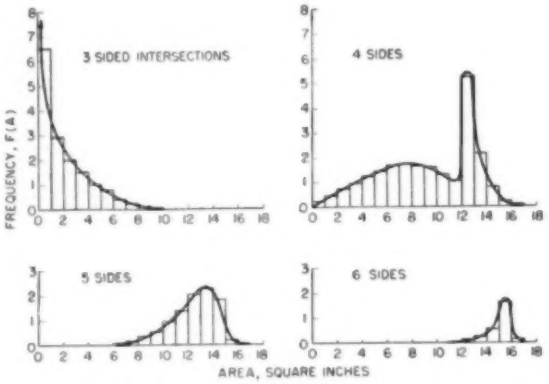


Fig. 7—Distribution of areas for 3, 4, 5 and 6-sided intersections of a random plane with a cube.

figure and thus has no particular significance for irregularly shaped polyhedrons.

The minimum, average, and maximum areas of the pentagonal dodecahedron (Fig. 9) increase with the number of sides of the section. Distribution curves for six and eight-sided intersections are slightly skewed as a result of a geometrical coincidence.

The curves for these three regular polyhedrons are useful in predicting the types of curves that might be obtained for the average metal grain. It is clear that the larger the number of faces on a grain, the larger will be the possible number of sides on an intersection. Since the faces on a metal grain are not necessarily parallel and are different sizes and have from three to about eight edges, there are fewer possibilities for the peculiarities in distribution that arise in regular polyhedrons. For the average grain, the minimum, average, and maximum area would increase more regularly with the number of sides of the intersection, and the frequency distribution of areas would be more normal. For polyhedrons of twelve to fourteen faces, the fre-

quency of occurrence of five, six, and seven-sided intersections would still be high, and intersections of ten or more sides would be exceedingly rare.

The plane distribution curves of areas, irrespective of the shapes of the intersections, are obtained by summing the above curves. For the four polyhedrons illustrated in Fig. 2, the distribution curves of areas are plotted in Figs. 10 to 13. All four curves are characterized by a rapid rise in frequency, $F(A)$, at small areas of intersection. Furthermore, each curve has a pronounced maximum in frequency at a value of $A/A_{max.}$, somewhere between 0.7 and 0.9, with the frequency dropping to zero at the largest area possible.

For direct comparison with plane distribution curves of the sphere and Scheil's statistical grain shape (Fig. 1), these frequency curves, evaluated experimentally in terms of areas, have been converted by calculation to frequency distributions of section "diameters" using the relationship derived earlier in this paper. One strikingly similar feature of the four plane distribution curves of section diameters in Figs. 14 to 17 is that the frequency does not gradually drop to zero as D approaches zero. Such a behavior is theoretically correct for a sphere, but is not to be expected in the case of polyhedrons or grains with edges meeting at sharp corners. This can be demonstrated in the following way.

For polyhedrons having three straight edges meeting at every corner, the small intersections will be triangles except for a few unique orientations of the cutting plane. For a given orientation, the intersections at a series of elevations are similar triangles whose areas increase with the square of the elevation and whose linear dimensions increase proportionally with distance,

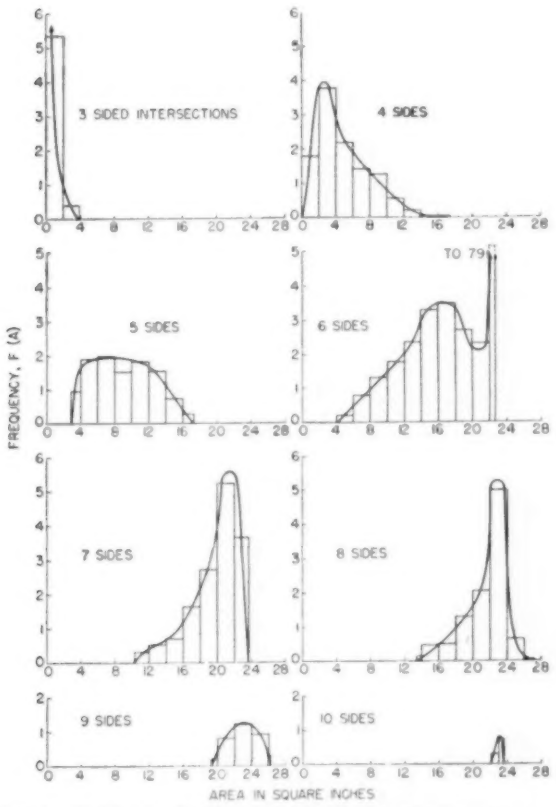


Fig. 8—Distribution of areas for 3 to 10-sided intersections of a random plane with a tetrakaidecahedron.

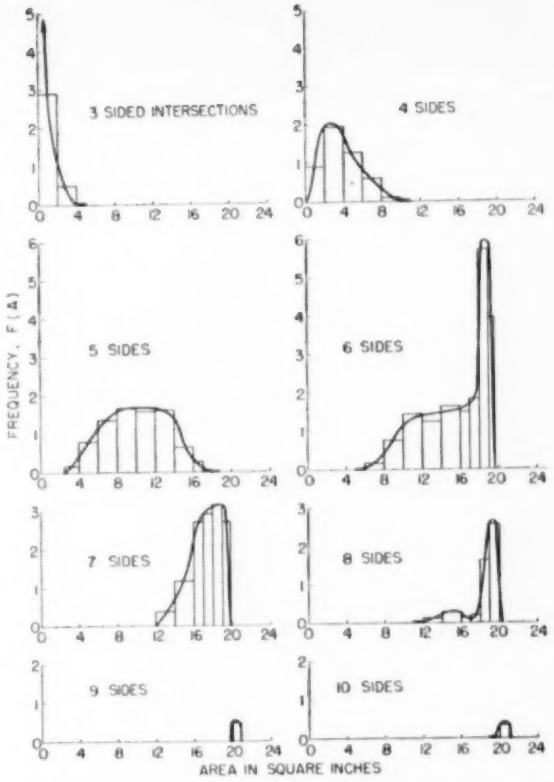


Fig. 9—Distribution of areas for 3 to 10-sided intersections of a random plane with a pentagonal dodecahedron.

$$D = k_1 x$$

The frequency of occurrence of areas with diameter D to $D + \Delta D$ from orientation 1 is proportional to Δx, that is $F_1(D) \sim \Delta x$
but

$$\Delta x = \Delta D / k_1$$

Therefore

$$F_1(D) \sim \Delta D / k_1$$

For equal increments of ΔD, $F_1(D)$ is a constant. The entire frequency curve at small values of D is obtained by summing such expressions for all orientations, and since the sum of a series of constants is still a constant, the $F(D)$ curve has a finite intercept and approximately zero slope at $D = 0$.

Distribution curves for the polyhedrons studied show a pronounced maximum in frequency at values of $D/D_{max.}$, between 0.85 and 0.95, and again the frequency drops to zero at the largest diameter of section possible. The detailed shapes of the frequency curves over the whole range of section diameters reflect differences in the compactness of the polyhedrons and their degree of symmetry.

The plane distribution curve for a statistical metal grain must have the four characteristics outlined above:

$$F(D) = \text{finite at } D = 0$$

$$\frac{dF(D)}{dD} = 0, \text{ at } D = 0 \text{ and } D/D_{max.} = < 1$$

$$F(D) = 0, \text{ at } D/D_{max.} = 1$$

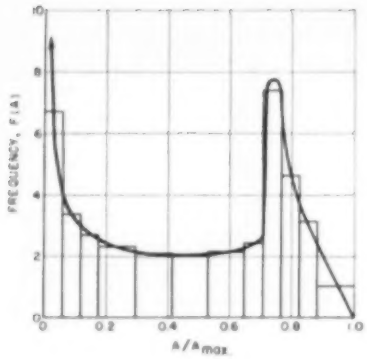


Fig. 10 — Plane distribution curve of areas for a cube.

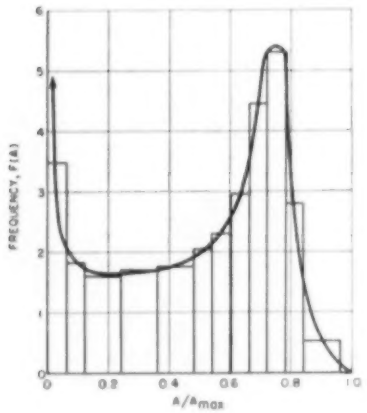
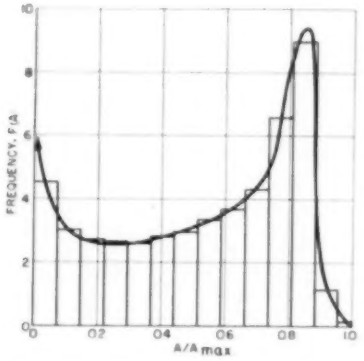


Fig. 11 (left)—Plane distribution curve of areas for special polyhedron.

Fig. 12 (right)—Plane distribution curve of areas for tetrakaidecahedron.



However, it would be expected from the lack of symmetry in the average metal grain that the maximum in frequency would not be as high or as narrow as in the case of the regular polyhedrons and that it would occur at a smaller value of the ratio D/D_{max}. Since occasional small faces are possible on a metal grain, the frequency curve of the average grain would rise more rapidly in the range of small values of the diameter. Aside from these generalizations, little can be said quantitatively about the plane distribution curve of the average metal grain until experimental data are obtained on grains from disintegrated samples to serve to evaluate such a curve.

Characteristics of Polyhedrons

In order to compare characteristics of the polyhedrons on a uniform basis, the dimensions of each were selected so that all the models had the same volume. For simplicity, it was assumed that the number of grains per unit volume, N_v, was equal to 1. The second entry in Table II gives the surface area of each polyhedron. The sphere naturally has the minimum surface per unit volume, but this represents an unattainable minimum in so far as metal grains are concerned because stacked spheres by themselves cannot completely fill space. A cube might be considered as an extreme in the opposite direction according to Kaiser,[6] excluding consideration of elongated or columnar grains. The three other more compact polyhedrons all have about the same surface per unit volume, indicating that the value is not too sensitive to actual shape for regular polyhedrons with twelve to fourteen faces. Since there is only about a 20 pct spread in areas between the sphere and the cube, it is reasonable to conclude that the surface area of actual grains can be approximated very closely by assuming them to be tetrakaidecahedrons, as was done by Rutherford, Aborn, and Bain.[7]

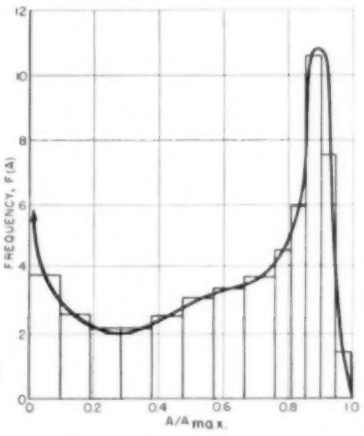


Fig. 13 — Plane distribution curve of areas for pentagonal dodecahedron.

Table II. Characteristics of Several Polyhedrons

	Cube	Special Polyhedron	Tetrakaidecahedron	Pentagonal Dodecahedron	Sphere
Volume	1	1	1	1	1
Surface of figure	6.00	5.34	5.31	5.30	4.83
r of inscribed sphere	0.50	0.53	0.54	0.56	0.62
Average r_i (based on intersections)	0.76	0.70	0.66	0.66	0.62
r of circumscribed sphere	0.87	0.75	0.70	0.71	0.62
Average cross-section area from distribution curve, $\overline{A}$	0.66	0.72	0.77	0.78	0.81
Maximum cross-section area, A_{max}	1.41	1.47	1.40	1.31	1.21
$A_{max}/\overline{A}$	2.14	2.05	1.83	1.69	1.50
Number of intersections per unit area, n: $1.\overline{A}$	1.51	1.39	1.30	1.29	1.24
Number of intersections per unit area, n: $2r_i$	1.52	1.40	1.32	1.32	1.24

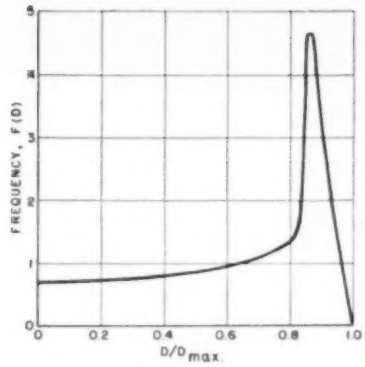


Fig. 14 — Plane distribution curve of section diameters for cube.

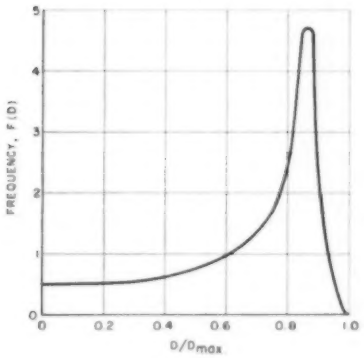


Fig. 15 — Plane distribution curve of section diameters for special polyhedron.

The entries for radii of inscribed and circumscribed spheres give a measure of the extent to which the corners of the polyhedrons protrude. The radius r_i is obtained by averaging the maximum elevation for all orientations of the polyhedron, giving each position its proper weight. On the average, grains whose centers lie within a distance r_i on either side of a sectioning plane will produce intersections. For unit area on the plane, the number of such intersections, n, is equal to the number of grains lying in a volume of $2r_i$ x 1 x 1, which is $2r_iN_v$. Since $N_v = 1$ by choice in the present instance, $n = 2r_i$.

One of the valuable uses of the distribution curves is that the average area of intersection, $\overline{A}$, produced by a given polyhedron can be calculated:

$$\overline{A} = \frac{\int_0^{A_{max.}} F(A)\, A\, dA}{\int_0^{A_{max.}} F(A)\, dA}$$

From the dimensions of a polyhedron, the maximum area of an intersection, $A_{max.}$, may be calculated. Sauerwald[8] and Gulliver[9] have pointed out that the ratio $A_{max.}/\overline{A}$ on the plane of polish of a metal sample is a measure of the uniformity of grain size in space. Formerly, there was no information on which to base an estimate of what this ratio should be for grains, except the value of 1.5 for spheres. For polyhedrons reasonably approaching actual grain shapes, it is seen in Table II that $A_{max.}/\overline{A}$ should lie in the range 1.8 to 2.0. The more the ratio for a given sample exceeds this theoretical minimum (for a single size in space) the greater is the range of sizes in space.

The number of intersections per unit area, n, equals $1/\overline{A}$ and also $2r_i$. Values of these quantities are listed in the last two rows of Table II. By the two independent methods of evaluation, n agrees closer than 3 pct, serving as a check on the accuracy of the distribution curves.

Interpretation in Terms of ASTM Grain Size Numbers

It has been long recognized that even with a constant grain size in space there would be a distribution of section sizes on a plane of polish. This fact was first expressed in quantitative terms, assuming grains were all spheres of a single size, by the plane distribution curve in Fig. 1. Rutherford, Aborn, and Bain[7] analyzed this curve in terms of ASTM grain size numbers in order to permit a clearer interpretation of its significance in terms readily understandable to the metallographer. In a similar manner, from the plane distribution curves in Figs. 14 to 17 and the known relation between grain section diameter and ASTM grain size numbers, the percentage of grain sections in different ASTM grain size groups has been determined for the various polyhedrons. The results for the polyhedrons, the sphere, and Scheil's statistical grain shape presented in Table III permit an evaluation of the extent of error introduced by the assumption that grains are spheres. As was expected, the latter assumption leads to predicting more large sections and fewer small ones than produced by polyhedrons approaching the shape of the average metal grain. The distribution curve for the cube obtained at Carnegie Institute of Technology resulting from only fifteen orientations leads to values in Table III that agree reasonably well with those based on the more accurately determined curve for the cube.

A person making a visual estimate of grain size is impressed not so much by the relative numbers of

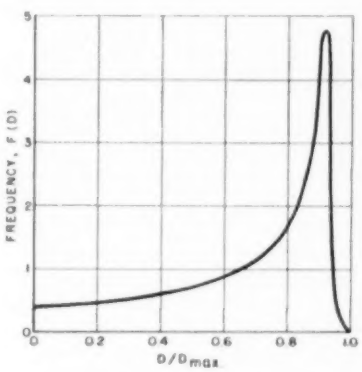


Fig. 16 — Plane distribution curve of section diameters for tetrakaidecahedron.

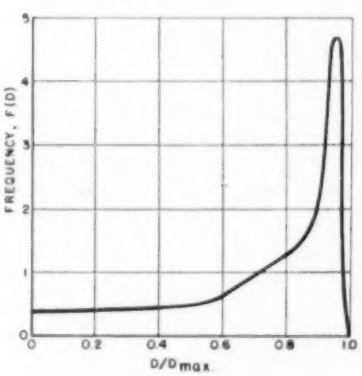


Fig. 17 — Plane distribution curve of section diameters for pentagonal dodecahedron.

Table III. Interpretation of Plane Distribution Curves of Several Polyhedrons in Terms of ASTM Grain Size Numbers

Shape	Intersections of ASTM Grain Size, Pct				Area Occupied by ASTM Grain Size, Pct			
	N	N+1	N+2	N+x	N	N+1	N+2	N+x
Cube	51	18	10	21	80	14	4.3	2.1
Cube (CIT)	53	16	10.5	20.5	81	13	4.4	1.4
Special polyhedron (CIT)	56	20	9.5	15	79	15	3.6	2.0
Tetrakaidecahedron	58	19	9.5	13.5	81	14	3.2	1.5
Pentagonal dodecahedron	63	17	8	12	87	10	2.1	0.5
Sphere	71	16	7	6	87	10	2	1
Scheil's statistical grain shape	59	18	9	14	84	12	2.5	1.1

each grain size present as by the relative areas occupied by each. Using the plane distribution curves again, it is possible to calculate the percentage of the section area occupied by grains in certain ASTM grain size groups. The results for the various polyhedrons also appear in Table III. Even with the extreme range of shapes from a cube to a sphere, the area occupied by the grains covering two ASTM grain size groups N and $N+1$ is between 94 and 97 pct of the total cross section. The large proportion of small grain section sizes usually seen on polished metallographic specimens can thus only be accounted for by a distribution of grain volumes in space. Actually, in all cases in which spatial distributions have been determined, a considerable spread about a mean size has been found.[4, 10]

Conclusions

1—The average and maximum number of sides on a plane section of a polyhedron increase with the number of faces on the polyhedron.

2—The distribution of plane section shapes of a polyhedron depends primarily on the number of faces and is not much affected by the shapes of the faces on the polyhedron.

3—With minor exceptions, the minimum, average, and maximum areas of intersections with a given polyhedron increase with the number of sides on the intersection.

4—Experimentally and theoretically, it has been shown for polyhedrons that the distribution of section diameters is a constant at small values of the diameter.

5—All four of the polyhedrons studied have a pronounced maximum in the plane distribution curve at less than the maximum diameter, and the frequency at the largest section possible is zero.

6—The plane distribution curve for an average metal grain would exhibit the same general characteristics found for the regular polyhedrons, except that the maximum in the frequency curve would be much broader because of the lack of symmetry in the grain shape.

7—If a material has a completely uniform equiaxed grain size in space, then on plane sections, 94 to 97 pct of the area will be occupied by grain sections covering only two ASTM grain size groups N and $N + 1$, regardless of the spatial shape of the grains.

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Corrections

In the January 1953 issue: TP 3417C. *Evaluation of the pH and Conductivity Methods of Slag Control* by P. D. S. St. Pierre, Pp. 42 and 43, in Tables I and III and in Fig. 4 the word microhm should read micromho.

In the February 1953 issue: TP 3449C, *Accelerated Solidification in Ingots: Its Influence on Ingot Soundness* by Edgar Marburg. P. 165, col. 1, 4th line from bottom, "*b*, *d*, and *g*" should read "*b'*, *d'*, and *g'*." P. 171, col. 1, paragraph 3, line 13, "Fig. 27" should read "Fig. 26."

In the February 1953 issue: TP 3435E. *Observation on Scaling of Iron* by W. J. Wrazej. P. 265. The following acknowledgment should be made: "This paper was published by permission of the Director-General of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Ont., Canada."

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aime NEWS

Second Annual Pacific Northwest Conference at Seattle Includes All Metals Divisions; Meeting Scheduled for May 14 to 16

The Second Pacific Northwest Conference, inaugurated last year out of a desire to serve the industrial expansion of that region, will be held May 14 to 16 at Seattle's Benjamin Franklin Hotel. Once a one day meeting, the gathering of the Industrial Minerals Div. and the Metals Branch has grown rapidly in scope. Sponsored by the AIME branches, divisions, committees, and supported by members, a cordial invitation has been extended to all mining and metallurgical people to attend.

Many excellent papers will be found in the Extractive Metallurgy and Physical Metallurgy Sessions.

Electric furnace men in the Pacific Northwest area will be especially interested in the Iron & Steel Session. In keeping with the special effort to attract and encourage students to the conference, mineral and metallurgical industries in the area are providing funds to pay for student luncheons and banquet. Students will not be charged a registration fee.

Engineering Education round table conference will cover the trend toward inclusion of additional fundamental science, especially physics, chemistry, and mathematics in metallurgical curricula. Representatives from government and private industry, cognizant of the needs of physical metallurgy, chemical metallurgy, and mineral dressing, will participate.

The Get Acquainted Coffee Hour will sound the opening note in the round of activities planned for the Women's Auxiliary. A theater party has been arranged, along with a luncheon and style show.

One of the outstanding scheduled events will be the address by George Vincent, public relations officer of the Aluminum Co. of Canada, at the metals luncheon, Saturday, May 16. His subject will be *Alcan's British Columbia Developments*, dealing with the Kitimat-Kemano project now under construction. The Alcan project promises to be one of the world's major aluminum centers when completed.

THURSDAY, MAY 14

1:30 pm

Plant Visits

Pre-registration necessary. A choice of several will be available including, Boeing Airplane Co., Bethlehem Pacific Coast Steel Corp., Tacoma Smelter.

FRIDAY, MAY 15

9:00 am to 2:00 pm

Industrial Minerals Div.

Chairman: Milnor Roberts, Mining Engineer, Seattle, Wash.

Analytical Shortcuts by Use of the Spectrograph: Thomas Matthews, State Dept. of Geology and Mineral Industries, Portland, Ore.

Use of Fuels and Electricity in Industrial Minerals Operations in British Columbia: J. W. McCammon, Mineral Engineer, British Columbia Dept. of Mines, Victoria, B. C.

Reopening of the Wilkeson Property in Pierce County, Wash., to Produce Metallurgical Coking Coal: E. R. McMillan, Mine Production Engineer, Northwestern Improvement Co., Seattle, Wash.

Lightweight Aggregate Production from Pacific Northwest Clays and Shales: J. I. Mueller, Associate Professor, Ceramic Engineering, Howard Shapiro and Roger R. Riley, Fellows, Ceramic Engineering, University of Washington, Seattle, Wash.

Summary of the Industrial Minerals and Rocks and the Fuels of the Pacific Northwest Including British Columbia: Milnor Roberts, Mining Engineer, Seattle, Wash.

Natural Gas for the Pacific Northwest: H. R. Seykota, Products Sales Manager, Portland Gas & Coke Co., Portland, Ore.

Diatomaceous Earth in Washington: R. C. Vervaeke, Quincy Corp., Quincy, Wash.

9:00 am

Iron and Steel Div.

Chairman: James T. Gow, Chief Metallurgist, Electric Steel Foundry Co., Portland, Ore.

Deoxidation vs Degasification of Alloy Steels Made in Basic Electric Furnace: A. L. Ascik, Works Manager, Seidelhuber Steel Rolling Mill Corp., Seattle, Wash.

Sampling Methods at Furnace for Composition Control: V. E. Belusko, Metallurgist, Electric Steel Foundry Co., Portland, Ore.

Subject Open: Alexander Finlayson, Consulting Metallurgist, Seattle, Wash.

Refractory Practices at Vancouver Steel Co.: G. R. Heffernan, General Superintendent, Vancouver Steel Co., Ltd., Granville Island, Vancouver, B. C.

Use of the Fluidity Test for Temperature Control: Charles Locke, General Manager, Atlas Foundry & Machine Co., Tacoma, Wash.

Some Experiences with the Lead Antimony Group Impurities in Iron and Steel: T. R. Stanley, Plant Superintendent, Foundry, Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C.

12 m

Industrial Minerals Luncheon

2:00 pm

Extractive Metallurgy Div.

Chairman: P. R. Benson, General Superintendent, Tacoma Smelter, Tacoma, Wash.

Production of Zirconium: E. Don Dilling, Chief of Rare Metals Branch, Bureau of Mines, Albany, Ore.

New Kaiser Aluminum Plant at New Orleans: C. P. Love, Manager, Kaiser Aluminum & Chemical Corp., Tacoma, Wash.

Recent Additions to Tacoma Smelter: G. E. Sigler, Assistant Manager, American Smelting & Refining Co., Tacoma Smelter, Tacoma, Wash.

Safety in Your Job: O. T. Gallagher, Personnel and Safety Director, American Smelting & Refining Co., Tacoma Smelter, Tacoma, Wash.

Utilization of Sulphur Dioxide: E. G. N. Player, Assistant Superintendent, Tadanac, Dept., Consolidated Mining & Smelting Co., of Canada Ltd., Trail, B. C.

SATURDAY, MAY 16

9:00 am to 2:00 pm

Physical Metallurgy

Chairman: W. W. Wiltschko, Aluminum Co. of America, Vancouver, Wash.

Statistical Treatment of Phase Transformations: Dan McLachlan, Jr., University of Utah, Salt Lake City, Utah.

Grain Growth of the Beta Cu-Al Phase: S. A. Duran, State College of Washington, Pullman, Wash.

High Temperature, High Pressure Oxidation of Metals II Tantalum in Oxygen: William McKewan and W. Martin Fassell, Jr., University of Utah, Salt Lake City, Utah.

High Temperature, High Pressure Oxidation of Metals III Zirconium in Oxygen: R. C. Peterson and W. Martin Fassell, Jr., University of Utah, Salt Lake City, Utah.

Zirconium-Silver System: R. S. Kemper and O. G. Paascho, Oregon State College, Coravallis, Ore.

Mechanics of Seizing in Metal Wear: Harry Czyzewski, Metallurgical Engineers, Inc., Portland, Ore.

Some Manganese Base Ferromagnetic Alloys: R. Butters and W. M. Armstrong, University of British Columbia, Vancouver, B. C.

X-ray Spectroscopy and X-ray Diffraction: James I. Mueller, University of Washington, Seattle, Wash.

Metallurgical Aspects of Small Gas Turbine Engines: W. L. Slosson, Boeing Airplane Co., Seattle, Wash.

12 m

Metals Branch Luncheon

Speaker: George Vincent, Public Relations Officer, Aluminum Co. of Canada

Alcan's British Columbia Developments

2:00 pm

Engineering Education

Chairman: F. A. Forward, Dept. of Mining and Metallurgy, University of British Columbia, Vancouver, B. C.

7:00 pm

Banquet

New England Regional Conference at GE Laboratory, April 23

THE Seventh Annual New England Regional Conference of the Institute of Metals Div., AIME, is scheduled to be held at the General Electric Research Laboratory, The Knolls, Schenectady, N. Y., Apr. 23 to 25, 1953.

The program will open on Thursday afternoon with sessions on *Deformation* and *Research in the Schenectady Area.* An *Extrusion* session followed by a tour of the GE Laboratory are planned for Friday. The Banquet is scheduled for 7 pm Friday at the Hotel Van Curler, tickets will cost $5. The speaker for the evening will be Dr. Katherine Blodgett. The last conference session, *New Techniques in Metallurgy*, will take place Saturday morning.

Registration will be at the General Electric Research Laboratory Thursday, April 23, from 1 to 2 pm. Fee for the Banquet and registration will be $6. Fee for registration alone will be $2. AIME Student Associates may register free of charge, while nonmember students will be charged $1.

Chairman of the Conference Committee is J. H. Moore, National Research Corp. Serving with him on the Committee are W. H. Sharp, Pratt & Whitney Aircraft, Vice-Chairman; F. H. Wilson, American Brass Co., Secretary; L. P. Tarasov, Norton Co., Treasurer; A. I. Blank, Chase Brass & Copper Co., Past Chairman; Dan Cushing, consultant metallurgist; W. D. Robertson, Yale University; W. L. Stearns, Bridgeport Brass Co.; L. W. Thelin, Chase Brass & Copper Co.; M. B. Bever, MIT, and G. P. Swift, consulting engineer. J. E. Burke, Knolls Atomic Power Laboratory, and T. W. Landig, Research Laboratory, were GE representatives.

All noncitizens except Canadians attending the Conference must request approval of visit to the laboratory. Please write: J. P. Garey, IGE, Room 600, Building 36, Schenectady Works, Schenectady, N. Y. Letters should include name, nationality, foreign residence and city, affiliation in the U. S., residence and city.

There are a limited number of single and double rooms available and all planning to attend the meeting are requested to write directly to the Hotel Van Curler, Schenectady, N. Y. for room reservations, mentioning the AIME New England Regional Conference.

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AIME Continues to Strengthen Financial Position As 1952 Surplus of $18,000 More than Doubles Previous Year

The following table indicates how the AIME income in 1952 was derived and for what purposes it was spent, both as to totals and on a per member basis. Notes following the table are intended further to clarify the data.

Income

		Total	Per Member	Pct of Income
1.	Dues	$314,886	$15.28	53
2.	Initiation fees	21,292	1.03	4
3.	Advertising in journals	182,516	8.86	31
4.	Sales of journals	28,135	1.37	5
5.	Sales of Petroleum Statistics	1,917	0.09	—
6.	Sales of Transactions volumes	28,942	1.40	5
7.	Other sales	11,135	0.54	2
8.	Interest	2,025	0.10	—
9.	Miscellaneous	2,532	0.12	—
	Total	$593,381	$28.80	100

Expense

				Pct of Expense
10.	Local Sections	$17,736	$0.86	3
11.	Divisions and branches	62,113	3.02	11
12.	Institute activities	32,426	1.58	6
13.	Library assessment	5,913	0.29	1
14.	Journals	261,402	12.69	45
15.	Transactions	17,597	0.85	3
16.	Petroleum Statistics	2,220	0.11	—
17.	Directory	20,542	1.00	4
18.	Other publications; reprints	9,467	0.46	2
19.	Secretary's office	32,464	1.57	6
20.	Business office	71,116	3.46	12
21.	Pensions, etc.	12,293	0.60	2
22.	Insurance	592	0.03	—
23.	Furniture and fixtures	6,869	0.33	1
24.	Miscellaneous	22,565	1.09	4
25.	Total	$575,315	$27.92	100

In the tabulation, the per member data are obtained by dividing the total amounts by 20,607, a figure that includes 1964 Student Associates.

1. This includes all the cash dues received from new and old members of all grades.

2. All cash initiation fees received from new members and partial payments on outstanding balances of men elected previously.

3. Net income received from advertising in the three monthly journals, of which $94,810 came from MINING ENGINEERING, $50,670 from JOURNAL OF METALS, and $37,036 from JOURNAL OF PETROLEUM TECHNOLOGY. In 1951 the figures were, respectively, $72,273, $39,844, and $31,564.

4. Individual sales of current and back issues, nonmember subscriptions, and multiple member subscriptions.

5. Cash received from the sale of this volume.

6. Sales of current and old volumes of Transactions. In the case of old volumes a deduction of $1.60 as a credit to inventory is made.

7. Sales of all other printed matter except special volumes sponsored by certain Funds in which case the Fund is credited with the income less a handling charge. Includes a considerable sale of preprints and reprints of technical papers.

8. Interest on securities held by the AIME and income from the Hayden Fund; does not include dividends and interest from certain Funds whose income reverts to those Funds.

9. Voluntary contributions, net income on outside book sales, cash discounts taken on bills paid, minor items.

The total income compares with $522,076 in 1951, an increase of $71,305.

10. Consists of appropriations to Local Sections; traveling expenses of delegates from Local Sections to the Annual Meeting; and a rebate of $2 of the initiation fee paid by any new Member or Associate Member (not including changes of status) in areas embraced in Local Sections.

11. Includes all appropriations made to Divisions and Branches, and salaries and expenses of paid Division and Branch officers; salaries and expenses of the Field Secretary in Salt Lake City; and rental paid for office space in Dallas and New York used by Branch Secretaries and their staffs.

12. Includes salaries, expenses, and rental space occupied by the staff at Institute headquarters devoted to securing new members and processing and filing all applications; also the net cost of meetings not properly chargeable to Branches, Divisions, or Local Sections, or borne by them.

13. Net AIME contribution to the support of the Engineering Societies Library. The balance of the Library assessment comes from interest on the James Douglas Library Fund of $106,000, amounting to $4500.

14. Includes salaries and all expenses of the editorial and advertising staffs of the three journals; rental of office space used by the staffs; paper, printing, binding, and mailing. Net cost can be obtained by subtracting items 3. and 4. from 14.

15. Cost of printing, binding, and mailing the current year's Transactions volumes, plus a percentage of the salaries of those concerned with their production. This is approximately the income received from sale of these volumes, included in the total of item 6.

16. A part of the cost of producing the volume; most of the remaining cost met from the Special Projects Fund of the Petroleum Branch.

17. Cost of printing and distributing the Directory supplement issued last June; cost of renting Flexoprint machines, salaries, labor of installation; estimated cost of printing and distributing Directory mailed with January 1953 journals. (Future Directories should cost about half this.)

18. Covers making reprints of papers appearing in the monthly journals, supplied free to authors and for sale.

19. Salaries, travel, and incidental expenses of the Secretary's office; rental of space used.

20. Salaries, rental, and miscellaneous expenses of the Business Office, including accounting, Addressograph (in part), filing, orders, change of address, purchasing, shipping (in part), reception, duplicating, and Flexoprint operations. In some instances a part of these expenses are charged to other items of expense.

21. Pensions and annuities, and certain severance payments for the staff are included. Noncontributory insurance and annuity policies are carried for AIME employes of more than five years' service. Income from any canceled policies is credited to this item.

22. Various types of insurance are carried.

23. Major items of furniture and fixtures are capitalized and during 1952 10 pct depreciation was charged on new equipment purchased. On old equipment, 20 pct depreciation was charged in this item.

24. Major items in this account were: Postage and supplies, $4762; write-off to accounts receivable (much of which it is hoped can be collected), $3691; New York disability taxes, Blue Cross subscriptions for staff members, and AIME share of Social Security taxes, $3723; labor expense (nonrecurring) in in-

stallation of new Addressograph system and cutting and tabbing some 21,000 new stencils, $3164; rearrangement of offices and partitions, construction, $2009; maintenance on furniture and fixtures, $1502; printing and inserting certain material in envelopes, $1320.

25. Compares with $514,067 in 1951, or an increase of $61,248. Major item in the increase was the cost of the Directory, which was not published in 1951.

It should be noted that the dues received per member are about $5 less than the dues paid by Members and Associate Members. In other words, the members in those two classes, who pay $20, are subsidizing to a certain extent the Junior Members who pay $12 dues but who receive all the privileges of membership; Student Associates, who pay only $4.50; Senior Members (of at least 30 years' standing and over 70 years old, who apply for this grade and who pay no dues at all but receive all privileges); and Honorary Members, who likewise pay no dues.

Name H. DeWitt Smith President-Elect for 1954

Henry DeWitt Smith was named President-elect for 1954 by the Nominating Committee for AIME Officers in 1954, S. S. Clarke, chairman, which met in Los Angeles on February 18. If elected, he will succeed L. F. Reinartz, who will serve as President in 1954. Other nominations of the Committee were as follows: For Vice-President, T. B. Counselman and Harold Decker; and for Director, Ralph E. Kirk, Carleton C. Long, P. J. Shenon, George D. Dub, E. R. Marble, and E. C. Babson.

Mr. Smith is vice-president of the Newmont Mining Corp., with headquarters in New York. He served as Director of the Institute, 1941-42.

Brief biographical sketches of the nominees will be published in the July issues of the journals. No letter ballot will be mailed to members unless supplementary nominations are received by September 1.

G. I. Brigden Elected Treasurer and Director

At the executive session of the AIME Board of Directors held in Los Angeles, George I. Brigden was elected a Director to fill the unexpired one-year term of L. F. Reinartz, President-elect. Mr. Brigden was subsequently elected Treasurer for one year to succeed Andrew Fletcher, who had filled the office since 1944. Mr. Brigden continues also as Controller.

Edward H. Robie was re-elected Secretary for a one-year term, and Peter J. Apol was reappointed Assistant Treasurer. The Executive Committee for the current year was appointed with the following personnel: Andrew Fletcher, Chairman; L. F. Reinartz, Vice-Chairman; T. B. Counselman, M. L. Haider, Philip Kraft. The new Finance Committee consists of the following: Gail F. Moulton, Chairman; A. B. Kinzel, Philip D. Wilson.

Bylaw Change Proposed

Pursuant to Art. XII, Sec. 1, of the Bylaws of the AIME, the following change in Art. II, Sec. 3, proposed by the Board at its February 15 meeting is hereby published for the information of members:

Present wording: Any Member or Associate Member may become, by the payment of $300 at one time, a Life Member or Life Associate Member and shall not be liable thereafter to pay annual dues. The money thus received shall be invested and only the income thereof used for current expenses of the Institute.

Proposed wording: Any Member or Associate Member may become, by payment at one time of twenty times the current normal annual dues for the grade in which he is enrolled, a Life Member or Life Associate Member, according to his current status at the time application is made. He shall not be liable thereafter to pay annual dues.

The Board will vote on this change at its meeting on May 13.

List Awards To Be Given at 1954 Meeting

Authorization was voted at the meeting of the Board of Directors, AIME, at the meeting on February 15, to grant the following awards at the Annual Meeting, Feb. 15 to 18, 1954: William Lawrence Saunders, Mining Medal; Anthony F. Lucas, Petroleum Medal; Charles F. Rand, Medal for Mining Administration (or other use of Fund income); Robert W. Hunt, Medal for an Iron or Steel paper; Robert H. Richards, Award in Mineral Beneficiation; J. E. Johnson, Jr., Award for Achievement in Pig Iron Metallurgy; Rossiter W. Raymond, Memorial Award for best paper published by AIME member under 33; Mathewson Gold Medal, for best paper in physical metallurgy.

Members wishing to nominate candidates for these awards should address the AIME Secretary, or the Chairman of the respective Award Committee.

IMD FALL MEETING PAPER DEADLINE

Apr. 15, 1953 is the deadline for all Institute of Metals Div. papers that are to be presented at the AIME Fall Meeting.

AIME Directors' meetings in the coming year will be held as follows:

Mar. 18, 1953, 12:30 pm	Executive and Finance Committees	New York
Apr. 15, 12:30 pm		New York
May 13, 10 am	Board of Directors	Tulsa
June 17, 10 am		New York
July 15, 12:30 pm	Executive and Finance Committees	New York
Aug. 19, 12:30 pm		New York
Sept. 22, 6 pm	Board of Directors	Seattle
Oct. 21, 12:30 pm	Executive and Finance Committees	New York
Nov. 18, 10 am	Board of Directors	New York
Dec. 16, 12:30 pm	Executive and Finance Committees	New York
Jan. 20, 1954, 12:30 pm		New York
Feb. 14, 2:30 pm	Board of Directors	New York
Feb. 16, 5 pm		New York

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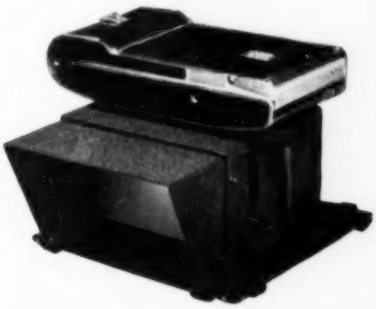

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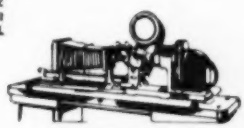

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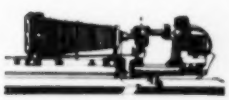

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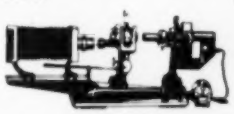

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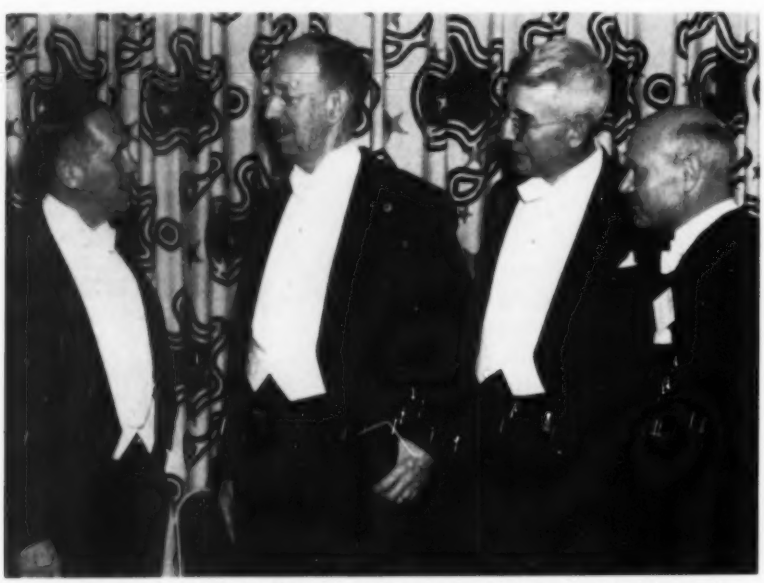
Conferees take a break during the meeting of the Metals Branch Council. From the left around the table are: Ernest O. Kirkendall, Metals Branch Secretary; Kenneth C. McCutcheon, Metals Branch Council Chairman; Ronald R. McNaughton, incoming EMD Chairman; Roy O'Brien, AIME Field Secretary; Walter A. Dean, outgoing IMD Chairman; Carleton C. Long; D. S. Eppelsheimer; Theodore Counselman, Institute Director; and T. D. Jones, outgoing EMD Chairman.

Southern California Section Sponsors "1953 Annual Meeting" Acclaimed Success By Technical and Social Attendees

CLEAR sunny skies that prevailed all through the 175th General Meeting of AIME were not the least of the details that resulted from the many months and man-hours of planning by the Southern California Local Section. Some 2600 persons left the 1953 Annual Meeting technically enlightened, having had a choice of over 300 papers presented by 400 authors to listen to, learn from, and criticize. During the meeting, Mike Haider turned over the Presidency of AIME for 1953 to Andrew (Drew) Fletcher.

The Council of Section Delegates started the first of the official proceedings with their all day meeting on Saturday, February 14. The Board of Directors met on Sunday, as did the Student Relations Committee, and the MIED. Most technical sessions started Monday morning.

On Monday, the Welcoming Luncheon was the opening of business-social activities, all of which were done in the Hollywood manner. President Haider presided at the Luncheon, and introduced Henry Mudd, who officially welcomed the group on behalf of the Southern California Local Section. In essence he remarked that it was wonderful to play host for the Annual Meeting despite the large volume of work involved. During introduction of the head table guests, Incoming President Fletcher was formally introduced and Desmond F. Kidd, President of the Canadian Institute of Mining & Metallurgy, extended greetings to the AIME on behalf of CIM.



Andrew Fletcher, 1953 AIME President, left, chats with three Past Presidents of the Institute during an informal moment prior to the Annual Banquet. The Past Presidents are L. E. Young, 1949; Jerry Peirce, 1951; and M. L. Haider, 1952.

Student prize awards of $100 each were made to William F. Hofmeister in the graduate div. and David F. Drinkhouse in the undergraduate div. Similar awards were made in absentia to Bruce W. Gilbert in the graduate div. and Benjamin C. Allen and Marvin A. Kunde in the undergraduate div.

Two membership contest awards are given annually by the President. The President's Banner is given to the Local Section gaining the greatest percentage of new members, and the Gavel, for the Local Section with the largest total of new members. The reason for the two awards is that the large and small section could be equally eligible. However, the Southwest Texas Section walked off with both awards, the result of intensive campaigns. Perhaps other Local Sections would do well to borrow a page from the methods book of this fast growing section. The Section also threatened to repeat this feat next year.

A. C. Rubel introduced Gov. Dan Thornton of Colorado, luncheon speaker. Gov. Thornton spoke on *Restraints or Responsibility*, with the major premise that if businessmen hold themselves responsible for carrying on the system of free enterprise, there need not be Government regulation. He stated that both he and the mining industry were firm believers in the free competitive enterprise system, and that the mining industry was built on those three key-

stones — freedom, competition, and enterprise. He advocated, "For government restrictions, let us substitute individual responsibility, for state control let us substitute self control." Gov. Thornton went on to suggest a four point program. First, incentive must be put back into private enterprise — and individuals must be able to make a reasonable profit from capital invested and effort expanded. Second, it must be realized that government has its proper place in the mining industry, but that place should be in technological research in production and utilization methods of our basic mineral resources. The third point is a fair tax system, which must not be so severe as to discourage risk capital, and not so lenient that the industry is not paying its just share of the cost of government. The last point of the Governor's program was the effect of good conservation practices upon the overall economic condition of the nation. Good conservation methods and practices are good business, he said.

Monday evening, preceding the stag-smoker, a cocktail party was provided for all meeting attendees by the Southern California Local Section, with the cooperation of many companies in the mining, metals, and petroleum fields. Headline attractions for the smoker were Edgar Bergen and Charlie McCarthy, with the Sportsmen's Quartet and other acts.

At the annual Institute business meeting on Tuesday afternoon, yearly reports were presented on AIME activities and branches. At the close of the session, Andrew Fletcher, with the aid of Jerry Peirce and Erle Daveler, was inducted by Mike Haider in to the Presidency of AIME for 1953, in a simple ceremony. Publicly, the new President does not officiate until the close of the Annual Banquet.

Highlights Tuesday evening were the Branch Dinners, followed by the Informal Dance. Ken McCutcheon presided at the Metals Branch Dinner, and Metals Branch Medalists and award winners were honored guests at the head table. Leo Reinartz, President-Elect for 1954, gave a brief summary of the accomplishments of the Branch. A. T. Cape introduced as Speaker for the evening, Walter T. Wells, partner of Lane Wells Co. Mr. Wells spoke on the subject of building a business, and drew largely from his personal experience. His talk was stimulating in that he advocated there was still opportunity for those who really had a useful contribution to make to industry.

After the Branch Dinners, conferees and their ladies repaired to the Ball Room of the Biltmore Hotel for the Informal Dance. Few attending could resist the music of Freddy Martin and his Orchestra, and the dance floor was always filled. After midnight, breakfast was served.

T. D. Jones presided at the first of what will be annual luncheons of the Extractive Metallurgy Div. Speaker at the luncheon was Dean Curtis L. Wilson, who did much to make this event the success it was.

Wednesday evening, the last and most important of the social affairs took place. With the Annual Banquet, always impressive, the outgoing President presents the Institute Awards of the year, and then unshoulders the tremendous responsibilities of his office, transferring them to the new President. No retiring President has failed to breathe a sigh of relief at being released to carry on only his regular duties; but all have made their contribution to the Institute and its members, and feel that by serving the minerals industry, they have themselves gained.

Retiring President Haider presented the following Medals and Honors at the Banquet: The Charles F. Rand Medal to Eugene Holman, president,

Michael L. Haider, 1952 AIME President, looks on as Kent Van Horn, 1953 IMD Lecturer, receives scroll and congratulations from Walter A. Dean, IMD Chairman.

Outstanding social event of the Annual Meeting this year was the Metals Branch Dinner, held in the Los Angeles Room of the Hotel Statler. K. C. McCutcheon, Metals Branch Council Chairman, acted as toastmaster.

Andrew Fletcher watches as Joseph Winlock, Howe Memorial Lecturer, center, and Kenneth McCutcheon exchange handclasps following Mr. Winlock's presentation.

Standard Oil Co. (New Jersey); the Anthony F. Lucas Award to Morris Muskat, technical assistant to the vice-president of production, Gulf Oil Corp.; the Rossiter W. Raymond Memorial Award to A. N. Holden, research associate, Knolls Atomic Power Laboratory, General Electric Co.; the Robert H. Richards Award to Edward W. Engelmann, assistant general manager, Utah Copper Div., Kennecott Copper Corp.; the Robert W. Hunt Award to John Hugh Chesters, assistant director of research, The United Steel Companies, Ltd., England; Mathewson Gold Medals to Paul A. Beck, research professor, University of Notre Dame, Philip R. Sperry, research metallurgist, Kaiser Aluminum & Chemical Corp., and Hsun Hu, Institute for the Study of Metals, University of Chicago; and the J. E. Johnson, Jr. Award to Charles M. Squarcy, assistant superintendent, blast furnaces, Inland Steel Co. J. H. Chesters was absent.

With the keynote of brevity for the evening, Mike Haider expressed his appreciation for the cooperation given him during his term of office, and presented Andrew Fletcher, as speaker of the evening and AIME President. President Fletcher pledged himself to uphold the splendid examples set by his predecessors, and to continue and further the aims and objectives of the Institute. This was no idle boast, as the new President has for many years been in extremely close contact with the Institute as a Director and Treasurer. By their applause, the audience expressed their gratitude to Mike Haider, and their wholehearted support to Drew Fletcher. The formal ceremonies were closed with the traditional President's Reception. Dancing followed.

The Woman's Auxiliary duplicated the pace of the men's meetings with a complete and well rounded program of activities. Mrs. Harold J. Clark served as General Chairman of the Ladies' Entertainment Committee, with Mrs. M. L. Haider and Mrs. Andrew Fletcher as Honorary Chairmen. Included in the festivities were attendance at the Lux Radio Theater, Hollywood, Luncheon at the Farmers' Market, tour of Beverly Hills, followed by Tea and Reception at the Hilltop Estate of Mrs. Cooley Butler, and a Luncheon and Fashion Show. Business was attended to at the Annual Meeting on Tuesday morning, and a Round Table Discussion was held Wednesday morning.

It was unanimously agreed that the Southern California Local Section did themselves proud, and spared no effort or expense to make the Annual Meeting one that will long be remembered. The General Committee under the Chairmanship of Henry T. Mudd, with Nicholas A. D'Arcy, Jr., and Basil P. Kantzer as Vice-Chairmen, C. W. Six, Treasurer, and Blair W. Stuart, Secretary; Finance Committee, with James D. Hughes, Chairman; Welcoming Luncheon Committee, A. C. Rubel, Chairman; Reception Committee, William H. Geis, Chairman; Cocktail Party Committee, Samuel F. Bowlby, Chairman; Dinner-Smoker Committee, Kenneth B. Powell, Chairman; Informal Dance Committee, Thomas F. Edson, Chairman; Banquet Committee, Ian Campbell, Chairman; Registration Committee, Frederic S. Boericke, Chairman; Technical Sessions Arrangements Committee, Lawrence W. Chasteen, Chairman; Hotel Committee, John R. Pemberton, Chairman; Student Participation Committee, Paul Andrews, Chairman; Publicity Committee, Robert L. Minckler, Chairman; and Field Trips Committee, Henry Mulryan, Chairman; and all committee members, did an outstanding job.

The Metals Branch presented some 120 papers at the meeting, in 30 sessions. Sessions were held on Copper, Lead and Zinc; Recent Developments in the Constitution of Slags, Mattes and Molten Salts; Lead, Zinc, Antimony; Aluminum-Magnesium; Selection of Metallurgists; Physical Chemistry of Extractive Metallurgy; Symposium on Copper Smelting; Titanium and Uncommon Metals; Blast Furnace; Gases in Steel; Steel Production; Constitutional Diagrams; Titanium Properties; Titanium Constitutional Diagrams; Plastic Deformation; Physical Metallurgy; Research in Progress; Zirconium, Titanium Plastic Deformation; Symposium on Mechanism of Hardening of Alloys; Creep of Metals and Thermodynamics; and a Symposium on the Structural Use of Powder Metallurgical Parts.

Joseph Winlock, Budd Co., delivered the Howe Memorial Lecture on Tuesday morning. His subject was *Influence of the Rate of Deformation*

The Women's Auxiliary meeting was crowded to capacity, symbolizing the extensive program of activities arranged for the ladies at the Annual Meeting. Tours, theater parties, and style shows were only part of the week's whirl for the distaff side.

on the Tensile Properties of Some Plain Carbon Sheet Steels. Andrew Fletcher and Ken McCutcheon were Associate Chairmen for this event. The Annual Lecture of the Institute of Metals Div. was delivered by Kent R. Van Horn, Aluminum Co. of America. His topic was *Residual Stresses Introduced During Metal Fabrication.* M. L. Haider and Walter A. Dean served as Associate Chairmen.

Aluminum - Magnesium Session — Reported by H. W. St. Clair, U. S. Bureau of Mines. The joint session between the EMD and MED was a particularly successful venture. A very interesting and informative discussion of the current expansion in facilities for production of aluminum was given by Samuel W. Anderson, formerly Deputy Administrator for Aluminum in the Defense Production Administration and at present the newly appointed assistant secretary for Foreign Affairs, Dept. of Commerce. Mr. Anderson reviewed the circumstances leading up to the production expansion program, pointed out some of the problems generated by expanding production more than 100 pct in so short a time, and outlined the basis in which estimates were made of future requirements for aluminum.

A similar discussion on the reactivation of government owned magnesium plants and the outlook for production of magnesium was presented by F. J. Krenzke of Dow Chemical Co., who is superintendent of the government owned magnesium plant at Welasco, Texas.

The afternoon session featured three diverse papers on aluminum. The experimental alumina plant being operated by the Bureau of Mines at Laramie, Wyo., was discussed by H. W. St. Clair, who is in charge of the project. This project is part of a long range program by the Bureau of Mines to extend the technology of alumina production to the treatment of aluminum silicates which are much more abundant than bauxite. A very interesting paper was presented by R. W. Bayerlein, vice-president of the Nordberg Mfg. Co., on the development of radial gas diesel engines and their application for generation of power for reduction of aluminum. D. D. Blue, assistant chief of the light metals branch of the Bureau of Mines in Washington, D. C., summarized a recent study made by the Bureau of Mines on the power and raw materials requirements of the aluminum industry.

Physical Chemistry of Extractive Metallurgy luncheon found the diners renewing old friendships and discussing events of the past year. H. H. Kellogg served as luncheon meeting chairman.

Panel Discussion on Constitution of Slags, Mattes and Molten Salts—Reported by Herbert Kellogg, Columbia University. The past 20 years have seen the publications of scores of papers on the properties and behavior of slags in metallurgical systems. Just how complete and useful is the picture of slags derived from this work, was well illustrated by the one industrial member of the panel who described his efforts (only partly successful) to find practically useful relations by *tinker-toy* arrangement of today's knowledge. When the panel settled down to a closer examination of *constitution* it was apparent that research has barely scratched the surface of the subject. Not only was the term *base* as applied to slags lacking in accurate definition, but the panel could not even find a wholly acceptable definition of an *ion* in slags.

It was generally agreed the main gap in our picture of slags, mattes, and molten salts is the detailed knowledge of the ionic-molecular structure of the melt. To this end considerable attention was given to the study of slags by structure sensitive techniques such as electrical conductivity, applicability of Faraday's Laws, determination of transport numbers, electrode potential measurements, and the determination of viscosity and diffusion. Only by knowledge of this kind can a satisfactory model of the structure of high temperature liquids be derived, and therefrom a more reasonable and useful manner of expressing the large body of thermodynamic data.

It is believed that everyone, including the panel members, took away something valuable from this session, if not in factual information then certainly in a refreshed outlook on the proper orientation of research efforts on this subject. All of the panel members are to be congratulated on their contributions, both prepared and unprepared, and their willingness to *take down their hair* when the situation called for it, as it rather often did.

Joint Educational Session, MED and MBD—Reported by J. P. Spielman, Washington State Institute of Technology. This interesting and successful session was held with a full

T. D. Jones served as toastmaster for the First General Luncheon and Business Meeting of the Extractive Metallurgy Div. Curtis L. Wilson, dean, Missouri School of Mines and Metallurgy, was the principal speaker.

The Institute of Metals Div. Executive Committee luncheon was held in the Hartford Room of the Hotel Statler, with W. A. Dean, Division Chairman, presiding. Seated from left to right are: William E. Mahin, W. A. Dean, Ernest O. Kirkendall and Paul Beck. Standing are: Kenneth C. McCutcheon, A. B. Kinzel, Institute Director; Leo F. Reinartz, President-elect for 1954; J. S. Smart; Earl R. Parker; and John Neilson.

house; at least twice as many people would have been in attendance had the room been larger.

The first three authors discussed the scientific selection of personnel, the selection of students for training for the mineral industry, and the qualities of character and personality which industry looks for in young engineers. The discussion indicated a keen interest on the part of the audience. It was well established that the scientific selection of personnel by industry is a useful tool, but has definite limitations. Those who consider it a panacea for all ills of selection would be disappointed. Those who consider it another tool in the selection of personnel would find it extremely useful.

Discussion also disclosed that industry is not only interested in young men of good character and with leadership potential, but is carrying on extensive programs to strengthen and develop the most desirable characteristics in its young engineers.

Relative to the selection of students, it was brought out, that the stimulation of interest and desire in potential students tends to automatically select those students with the greatest chances of success.

An interesting report was given on the experience of MBD with summer employment of students. This presentation brought out a great number of questions with respect to the types of jobs available, salary range for summer employment, and the geographical distribution of these opportunities. Discussion also revealed that in some cases students have not been sufficiently considerate in the matter of notification of inability to accept employment which had been agreed upon.

The last paper at this meeting was a concise and well presented resume of the supply and demand for mining engineers projected into the next four years. This paper indicated a rather dark future in this area of specialization during this period. Several informal discussion groups met at the close of the meeting and continued to discuss these subjects until dinner time. This writer sincerely hopes that meetings of this kind will continue in the future.

Copper Session—Reported by John G. Leckie, American Smelting & Refining Co. Approximately 50 men attended the presentation of three excellent papers at the Copper session of the Extractive Metallurgy Div. which was held Monday afternoon.

N. Alston discussed the design, construction, and operation of the new copper anode casting plant at Garfield, Utah. The plant consists of five 240-ton furnaces and auxiliary equipment, and is now casting approximately 23,000 tons of copper anodes per month or more than any other plant in the world.

H. K. Spaulding presented a paper on the *Rehabilitation of Asarco's Perth Amboy Refinery*, which included the installation of many improved features, and which was done without materially affecting plant output.

H. A. Shaw's paper described operation of the 3-phase 60-cycle arc furnaces at the Kennecott refinery in Utah. This is the only copper refinery at which both anode and refined copper is continuously melted in arc furnaces, and then cast directly into the desired shapes without blowing, poling, or the use of an auxiliary induction furnace. An interesting discussion was given on the effects of electrode size on the melting rate, electrode consumption, wall temperature, and power factor of their furnaces.

Creep and Thermodynamics — Reported by O. Cutler Shepard, Stanford University. The different points of view of the various papers on creep give striking evidence of the complex nature of creep and the need for additional work in this field.

Hazlett and Parker examined in detail the early part of creep curves. They subtract the instantaneous strain upon loading from the total strain to obtain a *time-dependent strain* which they relate to time and temperature by an empirical equation. There is no separation of first stage and second stage creep in their work and they doubt the concept of second stage steady state creep. They state that under constant stress the creep rate continuously decreases until the initiation of failure. There was the general feeling among commentators that possibly the continuous decrease in creep rate is a peculiarity of the high strain rate, short times and limited temperature ranges investigated.

Sherby and Dorn reported on a thorough study of the creep of dilute solid solutions of aluminum. They found that the creep strain, during the period of minimum creep rate (second stage creep), is a function of *temperature-compensated time*. The temperature-compensated time concept involves an activation energy which appears to be of fundamental importance. By means of this relationship successful predictions of the variation in creep curves with variation in temperature have been made. They found that the effect of variable stress could not be accurately predicted because creep stress and creep strain affects grain substructure which, in turn, affects the creep rate. The Sherby and Dorn concept of temperature-compensated time appears reasonable and the work of these men will be watched with interest for further confirmation of their creep parameters.

Chang and Grant presented a study of grain boundary sliding and migration. Grain boundary sliding causes high stresses at grain intersections. Chang and Grant presented evidence that grain boundary migration relieves these stresses in pure aluminum and avoids intercrystalline creep failure. They found that alloying elements restrict grain boundary migration and they believe this allows

stresses to build up which cause intercrystalline creep failures in commercial alloys.

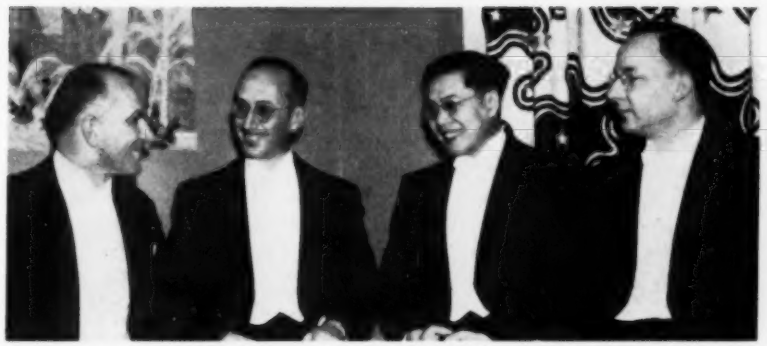
Two papers in the field of thermodynamics were presented, and both contributed additional information in difficult and important aspects of that field. Frye, Stansbury, and McElroy measured the rate of growth of pearlite in high purity Fe-C alloys. From this and other data, a rate equation was derived and an activation energy calculated. It is believed that this equation can be used as a guide for the study of the effect of alloying elements on the kinetics of the austenite-pearlite transformation. Further work on this subject is in progress by the authors.

Buttner, Udin, and Wulff determined the angle in thermal grooves which form in fine gold wires at 1300°K. From average values of the groove angle and from the value for the surface tension of gold, previously determined by the authors, they calculate the absolute grain boundary energy of gold at 1300°K to be 365 ± 59 dynes per sq cm. Further detailed studies by this technique, combined with X-ray identification of surfaces and orientations, are to be greatly desired.

Recent Developments in the Constitution of Slags, Mattes and Molten Salts — Reported by M. Tenenbaum, Inland Steel Co. Six papers were presented describing developments toward better understanding of experimental and commercial slag systems. The papers reviewed work on simple oxide slag systems from experimental studies as well as the complex systems involved in acid and basic open hearth and electric furnace operations.

R. Schuhmann, Jr. reviewed some results from his comprehensive works on the FeO-Fe_2O_3-SiO_2 slag system, with particular emphasis on areas involved in metallurgical processes. This review was followed by the presentation of a paper by H. Larson and J. Chipman demonstrating the influence of oxygen pressure in the atmosphere above simple oxide slags on the ratio, $\frac{Fe^{++}}{Fe^{++} + Fe^{+++}}$. This paper brought out the fact that the ratio is a function of slag composition as well as the oxygen pressure in the surrounding atmosphere.

Three papers were then read presenting data from commercial furnaces. In the first paper J. F. Elliott and F. W. Luerssen described the behavior of phosphorous and manganese during the flush period of basic open hearth heats. The authors concluded that the distribution of phosphorous and manganese in the complex basic open hearth system approached a tentative equilibrium which was determined, to a large extent, by the slag temperature. G. R. Fitterer presented an interesting review aiming to account for the oxygen consumed in acid open hearth bath reactions. It was brought out that it was possible to interpret the results observed in the acid open hearth process by considering oxygen that would be made available in ionic reactions.



Kent Van Horn, IMD Lecturer, left, chats with Mathewson Gold Medal winners Paul A. Beck, Hsun Hu, and Philip Sperry during informal session prior to the Annual Banquet.

In the final paper of the session, H. P. Rassbach discussed the recovery of manganese and chromium in the electric furnace process. Rassbach showed that the recoveries of these two elements was a function of both slag composition and temperature. Rassbach stressed the importance of close basicity control for optimum and uniform recovery of chromium and manganese in stainless steel melting.

Titanium and Uncommon Metals— Reported by Bruce W. Gonser, Battelle Memorial Institute. This session dealt with uncommon metals and extractive processes. Papers were given on germanium, beryllium, and on the application of ion exchange to the recovery of metals from solution. Possibly underestimating the drawing power of a session on the uncommon metals, the room allotted was soon filled to overflowing and remained so throughout.

A. P. Thompson, director of research for Eagle Picher Co., presented a paper on germanium production and in discussion mentioned the dilemma of a producer who hears many reports of the great need for a metal, yet does not receive firm orders in such volume that further expansion is justified. Possibilities for new sources of germania from Africa, and coal, were discussed by Oliver Ralston of the Bureau of Mines, the Chairman, and others.

Ion exchange as a tool of growing importance in metal recovery and metal operations was a fruitful subject for discussion. Unfortunately, F. H. Spedding of Iowa State College withdrew his paper on rare earth separation just before the meeting, but this was partially covered in a more general paper given by A. B. Mindler of the Permutit Co. Recovery of metals from dilute leaching solutions or wash water or spent electrolyte or various waste solutions were particularly stressed.

The effect on ductility of vacuum distillation of relatively high purity beryllium to remove oxygen was

Mrs. D. F. Hewitt, Mrs. Harold J. Clark, Mrs. Cooley Butler, and Mrs. Felix Wormser, 1953 President of the Women's Auxiliary, appear to be discussing the week's activities during a social event held at the Butler estate.

Leo Reinartz, 1954 President-Elect, left, Joseph Winlock, Howe Memorial Lecturer, and Abe N. Holden, Rossiter W. Raymond Memorial Award winner exchange notes on the meeting.

Clyde Williams, 1947 Past-President, left, and William E. Wrather, 1948 Past-President review the events of the meeting with J. E. Johnson, Jr., Award winner Charles M. Squarcy.

found by C. S. Pearsall of MIT to be minor. Electron bombardment was used to distill the beryllium—an unusual device. Of particular interest was the calculation of maximum oxygen that could be present in the product, since analytical procedures were undependable for determining a few parts per million.

Titanium and Uncommon Metals —Reported by N. C. Fick, Panel on Metals & Minerals, Dept. of Defense. In *Thermodynamic Equilibrium for Reactions Involving Titanium Compounds*, D. D. Wagman summarized the thermodynamic data available to date. A lively discussion period brought out that considerable work either underway or contemplated should bring forth much new thermodynamic data within the next year or two.

The oxidation of molybdenum is of practical importance since molybdenum is contemplated for high temperature applications. N. A. Gokcen presented information on the thermodynamic properties of the oxide.

G. M. Willis and F. L. Hennessy did not properly judge the distance between Australia and New York and the 3000 miles separating New York and Los Angeles. Their paper on Ag_2O-B_2O_3 did not arrive in time for presentation.

George Moore presented a paper on the *Preparation of High Purity Iron*. The current attempt, to produce iron of higher established purity than has been attained previously, employs the following principles: Purification of ferric chloride solution by ether extraction; conversion of the purified ferric chloride to ferrous chloride by reduction with high purity iron with subsequent purification of the ferrous chloride solution; recovery of metallic iron by electrolysis of the purified ferrous chloride with subsequent removal, from the cathode iron, of carbon and oxygen by annealing in hydrogen.

A small amount of iron containing less than 13 ppm total of metallic impurities has been prepared and some of its properties, e.g., indentation hardness and corrosion resistance, confirm the analytical evidence that this is iron of unusually high purity. However, it is not certain that the ideal process has been achieved; subsequent modification of some of the details of the production process has produced iron which, according to incomplete analysis, contains less metallic impurities.

One of the major difficulties encountered in this investigation has been the determination of impurities, in high purity iron, with the desired accuracy and precision.

This process for the production of high purity iron is still in the stages of experimental development, and it will be some time before enough stock can be accumulated to comply with any requests for iron of established super purity. The discussion brought out that swaged and annealed iron has rather good corrosion properties. It is as soft as commercially pure aluminum.

Titanium Constitutional Diagrams —Reported by Harold Margolin, New York University. The sessions on Titanium Constitutional Diagrams were guided by John P. Nielsen of New York University as Chairman and A. E. Flanigan of the University of California as Secretary. Papers presented appeared in the February supplement of JOURNAL OF METALS. Also included was the paper on *Martensite Habit Plane in Quenched Ti-Mn Alloys* by Y. C. Liu and Harold Margolin. This paper will appear in a later issue of the JOURNAL OF METALS.

Discussion of the constitution diagrams centered about the Titanium-Carbon, Titanium-Manganese and Titanium-Aluminum-Chromium systems. The Titanium-Carbon system from 0 to 20 pct carbon shows two reactions, a peritectic liquid solidification and a peritectic formation of alpha, the low temperature allotropic form of titanium. Questions were raised on the solubility of carbon in liquid titanium at the peritectic temperatures and of carbon in beta titanium at the peritectoid temperature since these solubilities are of interest from a commercial point of view. It was pointed out that the presence of oxygen and nitrogen may increase the solubility of carbon in beta titanium, but this effect is small. In view of the different results obtained by the discussers and the authors, it was felt that data from a third investigation would be needed to resolve the differences. This discussion is to be presented in written form.

The Titanium-Manganese phase diagram in the region up to approximately 68 pct manganese was presented. The diagram shows peritectic and eutectic solidification of liquid and the presence of two compounds. A question was raised as to whether the compound lower in manganese

The Executive Committee of the Extractive Metallurgy Div. held its breakfast meeting in the Hartford Room of the Hotel Statler. T. D. Jones presided over the session.

forms by peritectic or peritectoid reaction. Evidence for the latter is to be presented in a written discussion.

Included in the Ti-Al-Cr paper was a section on the M_s temperature of titanium-rich alloys. It was pointed out that microstructure data from commercial alloys showed a considerably lower M_s temperature than was reported for these alloys. Some data on this point is to be presented in written form.

The paper on *Martensite Habit Plane in Quenched Titanium-Manganese Alloys* reported that martensite forms along two planes of the beta-matrix $\{334\}_\beta$ and $\{344\}_\beta$. Determination of habit plane was made by both two surface and single-surface analyses and a number of interesting microstructures showing complex martensite structures were presented.

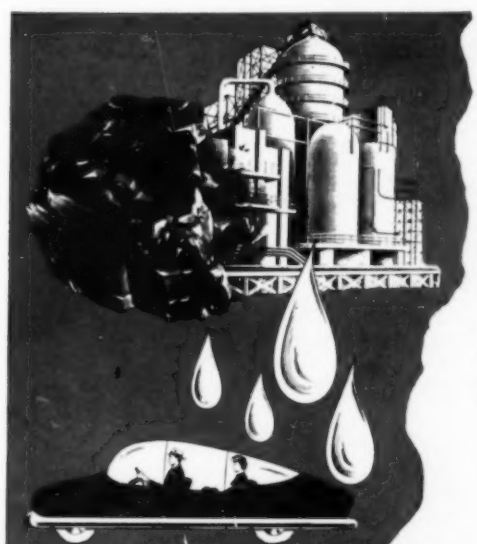
Social events provided proper balance to technical sessions. Music at the Informal Dance was supplied by Freddie Martin and his orchestra in the Ball Room of Los Angeles' Biltmore Hotel.

Steel Production—Reported by C. M. Squarcy, Inland Steel Co. L. T. Sanchez of the U. S. Steel Corp., Lorain, Ohio, presented interesting data showing how oxygen was beneficial to their operation in the Bessemer converter. Correlations between percent scrap in the charge and blow time were effectively presented. The relation between silica in the iron and blow time was also expressed.

C. W. Sherman presented the paper *Activity of Sulphur in Liquid Iron and Steel* by Sherman and Chipman. The work that had been done at MIT paralleled very closely the work accomplished at U. S. Steel Corp.

P. D. S. St. Pierre, of the Dept. of Mines and Technical Surveys, Ottawa, gave an excellent presentation *An Evaluation of the pH and Conductivity Methods of Slag Control.*

E. Marburg, U. S. Steel Corp., Pittsburgh, showed many excellent slides on ingot structure. The relationship of accelerated solidification in ingots to the ingot soundness was ably expressed by the author. From his illustrations it was noted that freezing played a major role in ingot solidification.



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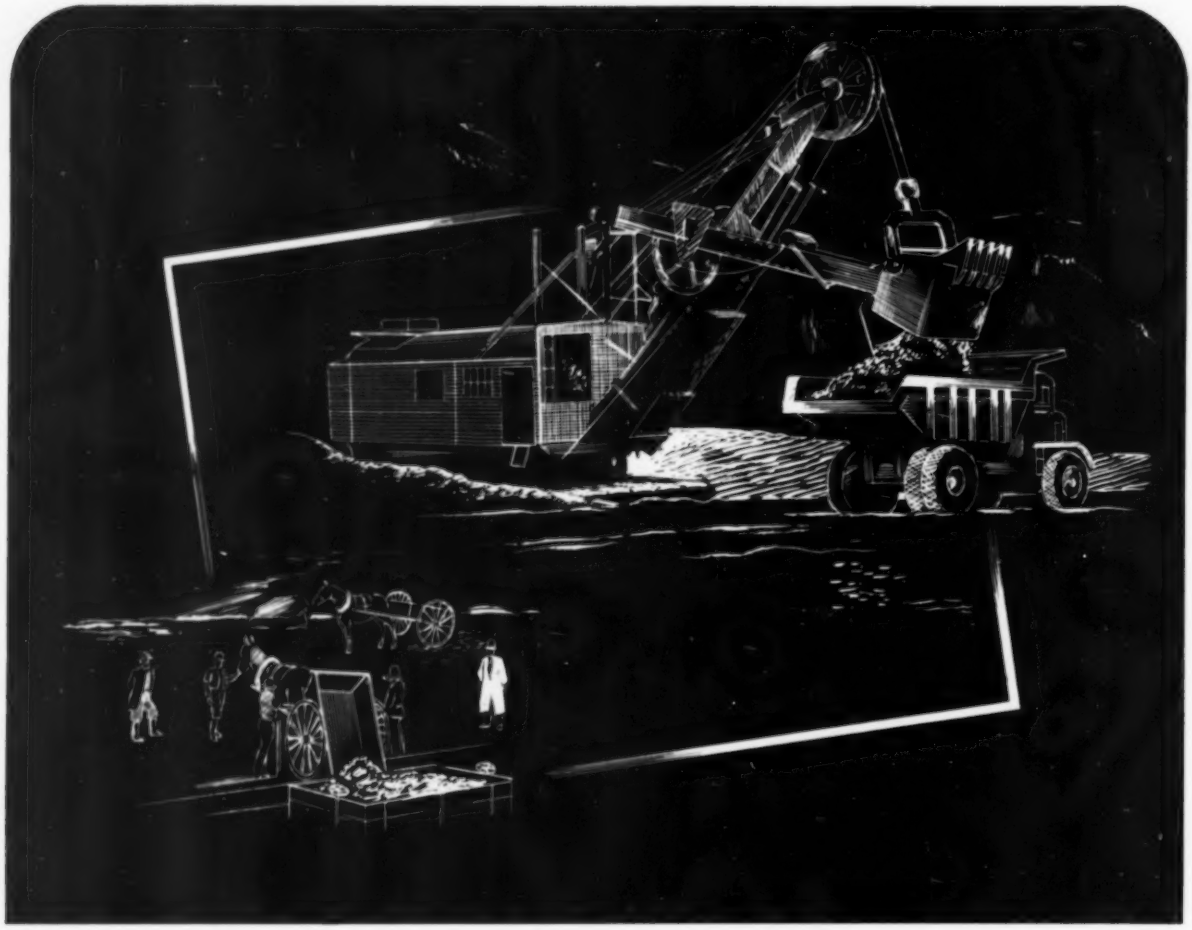

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— Coming Events —

April-May, Empire Mining and Metallurgical Congress, Australia and New Zealand.

Apr. 1, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Apr. 9-11, Lead Industries Assn., annual meeting, Greenbrier, White Sulphur Springs, W. Va.

Apr. 12-16, Electrochemical Society, Inc., spring meeting, Statler Hotel, New York.

Apr. 12-May 23, Empire Mining and Metallurgical Congress, Australia-New Zealand.

Apr. 18, AIME, Student Conclave and St. Louis Local Section, Missouri School of Mines.

Apr. 20-22, Metal Powder Assn., metal powder show and annual meeting, Hotel Cleveland, Cleveland.

Apr. 20-22, AIME, National Open Hearth and Blast Furnace, Coke Oven and Raw Materials Conference, Hotel Statler, Buffalo.

Apr. 21, Assn. of Consulting Chemists & Chemical Engineers, Inc., symposium and dinner, Hotel Belmont Plaza, New York.

Apr. 23-25, AIME, New England Regional Conference, General Electric Laboratory, Schenectady, N. Y.

Apr. 25-May 10, Liege International Fair, Liege, Belgium.

Apr. 26-29, American Institute of Chemical Engineers and **Chemical Institute of Canada,** Royal York Hotel, Toronto.

Apr. 27-28, American Zinc Institute, annual meeting, Hotel Statler, St. Louis, Mo.

May 11-14, American Mining Congress, coal show, Public Auditorium, Cleveland, Ohio.

May 14-16, AIME, Pacific Northwest Metals and Mineral Conference, joint meeting, Metals Branch and Industrial Minerals Div., Ben Franklin Hotel, Seattle.

May 14-23, International Petroleum Exposition, Tulsa.

May 18-22, National Materials Handling Exposition, Convention Hall, Philadelphia.

May 20, AIME, National Open Hearth Steel Committee, Western Section, field trip.

May 22, AIME, National Open Hearth Steel Committee, Eastern Section, plant visit, Bethlehem Steel Co., Bethlehem, Pa.

June 3-7, Chemical Institute of Canada, Windsor, Ont.

June 15-19, Basic Materials for Industry, conference, Hotel Roosevelt; exhibition, Grand Central Palace, New York.

June 29-July 3, ASTM, annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.

Sept. 21-23, American Mining Congress, Metal and Nonmetallic Mineral Mining Convention, Olympic Hotel, Seattle.

Oct. 7-9, National Assn. of Consulting Engineers, south central region, Mayo Hotel, Tulsa, Okla.

Oct. 8-9, National Conference on Industrial Hydraulics, annual meeting, Hotel Sheraton, Chicago.

Oct. 9, AIME, National Open Hearth Steel Committee, Eastern Section, fall meeting, Warwick Hotel, Philadelphia.

Oct. 15, AIME, National Open Hearth Steel Committee, Southwestern Section, fall meeting, Baker Hotel, Dallas, Texas.

Oct. 19-21, AIME, Institute of Metals Div., fall meeting, Hotel Allerton, Cleveland.

Oct. 19-23, National Metal Congress and Exhibition, Cleveland.

Oct. 27, Assn. of Consulting Chemists & Chemical Engineers, 25th anniversary annual meeting, Hotel Belmont Plaza, New York.

Oct. 28-31, AIME, El Paso Fall meeting, El Paso.

Oct. 29-31, National Council of State Board of Engineering Examiners, Annual Meeting, Plaza Hotel, San Antonio, Texas.

Oct. 30-31, AIME, National Open Hearth Steel Committee, Southern Ohio Section, Deshler-Wallick Hotel, Columbus.

Nov. 6, AIME, National Open Hearth Steel Committee, Pittsburgh Section, off-the-record meeting, William Penn Hotel, Pittsburgh.

CONGRATULATIONS:

To the United States Steel Corporation on this memorable occasion observed in 1952:

The FIRST heat of steel poured at U. S. Steel's new Fairless Works, Morrisville, Pa.

The Ross-Tacony Crucible Co. is proud that a ROSS SUPER STOPPER was used in pouring this commemorative heat.

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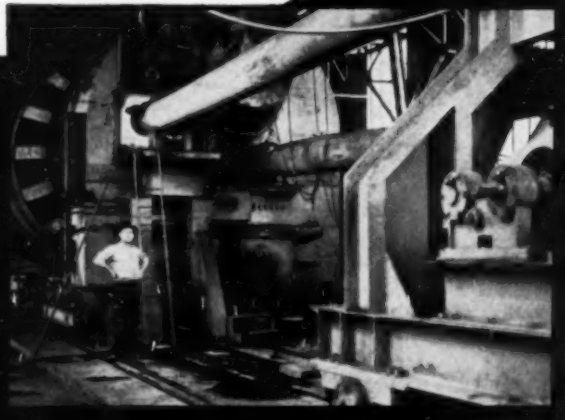

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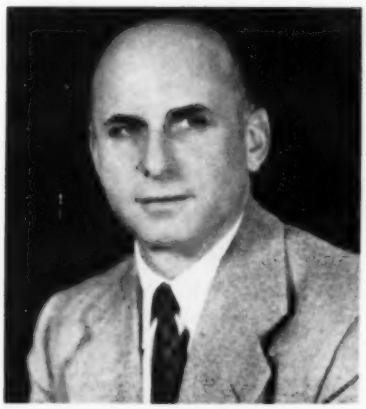
Personals



O. T. MARZKE

Oscar Theodore Marzke, superintendent of the metallurgy div., Naval Research Laboratory, has been named consultant to the director of research at the NRL in the fields of chemistry, electricity, mechanics, and metallurgy.

S. Feigenbaum has been named chief metallurgist for the Pittsburgh works of the Jones & Laughlin Steel Corp., Pittsburgh.

J. R. FREEMAN, JR.

John R. Freeman, Jr. has been appointed vice-president of metallurgy and research of the American Brass Co. Mr. Freeman had been technical manager of the firm.

William C. Ridge has been appointed works manager in charge of the manufacturing operation of the Trenton and Roebling, N. J. plants of the John A. Roebling's Sons Corp.

L. C. Perkinson has been elected vice-president of the American Cyanamid Co., New York.

John E. Thompson, Jr. was appointed assistant to the general superintendent, Gary, Ind., sheet and tin mill, U. S. Steel Corp.

Walter J. Koshuba is supervisor, metallurgical and ceramic development, General Electric Co., Cincinnati.

Richard W. Porter has been named general manager, guided missiles dept., General Electric Co., Schenectady.

Edmund T. Morris has been appointed assistant manager, atomic power div., Westinghouse Electric Corp., Pittsburgh.

Andrew B. Black has joined the Sherritt-Gordon Mines, Ottawa, Ont., Canada. Mr. Black had been associated with the Cerro de Pasco Corp., La Oroya, Peru.

William E. Norden, formerly with National Carbon-Eveready, S. A., Mexico, D. F., has joined Union Carbide International Co., New York.

Bernard B. Kunkle is assistant works manager, Phelps Dodge Refining Co., El Paso. He had been plant metallurgist for the company.

Oscar Pearson has joined the U. S. Steel Corp. as assistant general superintendent, Duquesne works, Duquesne, Pa.

Scott Turner, mining engineer, New York City, has been elected president of the Council of the American Institute of Consulting Engineers. **Charles E. DeLeuw** and **Elmer K. Timby** have been elected vice-presidents.

I. J. Groce, formerly of the U. S. Bureau of Mines, Albany, Ore., has accepted a position as chemical engineer with Metal Hydrides, Inc., Beverly, Mass.

Desmond A. Harry is associated with Bohn Aluminum & Brass Corp. as a metallurgist in the research div.

James E. Krajovic has been appointed purchasing agent of the Brosius div., Salem-Brosius, Inc., Salem, Ohio. Mr. Krajovic succeeds **Alfred G. Lewis,** who is retiring.

M. A. E. Mawby was elected president of the Council of the Australasian Institute of Mining and Metallurgy. Mr. Mawby is director of exploration and research Zinc Corp. Ltd.

Will G. Alexander has joined the Chavin Mines Corp., Lima, Peru. He had been associated with the Vanadium Corp. of America at Ricran, Peru.

Paul McVicker was appointed technical director of operations, Electro Metallurgical Co., a division of Union Carbide & Carbon Corp. His headquarters will be in Niagara Falls, N. Y. Mr. McVicker has been associated with the firm since 1926.

ALEXANDER GOBUS

Alexander Gobus, formerly with Sam Tour & Co., Inc., has joined the North American Philips Co., Inc., Mount Vernon, N. Y., as director of non destructive testing.

S. S. Goodwin was elected a vice-president of the New Jersey Zinc Co.

Paul E. Kelly, treasurer of the Superior Tube Co., Norristown, Pa., has been named vice-president.

Chester E. Grigsby has become a member of the board of directors, General Steel Castings Corp., Granite City, Ill.

Russel B. Caples, manager of Anaconda's Great Falls, Mont., reduction dept. since 1941 has been elected president and director of Anaconda Aluminum Co. Mr. Caples will make his headquarters in New York.

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Buehler specimen preparation equipment is designed especially for the metallurgist, and is built with a high degree of precision and accuracy for the fast production of the finest quality of metallurgical specimens.

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2. No. 1211 Wet power grinder with ¾" hp. ball bearing motor totally enclosed. Has two 12" wheels mounted on metal plates for coarse and medium grinding.

3. No. 1000 Cut-off machine is a heavy duty cutter for stock up to 3½". Powered with a 3 hp. totally enclosed motor with cut-off wheel, 12" x 3/32" x 1-1/4".

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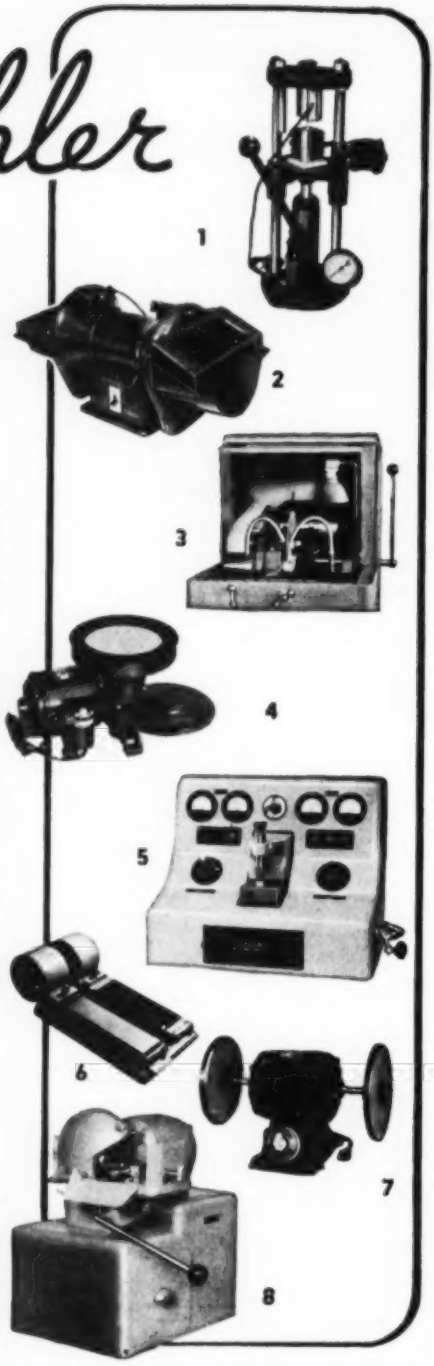

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E. M. WISE

Edmund M. Wise, in charge of precious metals and electronics section of International Nickel Co.'s development and research div., New York, has been honored by Inco for his 25 years of continuous service with the company.

Burton R. Buck has been appointed works manager of the Electro Metallurgical Co., div. of Union Carbide & Carbon Corp.

Elmer H. Schulz has been promoted to director of research and **Maurice J. Day** has been named assistant director for program development, Armour Research Foundation, Illinois Institute of Technology.

Ernest A. Remesch has joined the Foote Mineral Co. as superintendent of the new lithium processing plant at Sunbright, Va.

Max W. Demler has been appointed salesman, Minneapolis sales office, Harbison-Walker Refractories Co., Pittsburgh.

Obituaries

Appreciation of
C. H. Herty, Jr.
By L. F. Reinartz

With saddened hearts, we give expression to our deep sorrow and regret over the sudden passing away of our friend and co-worker, Dr. Charles H. Herty, Jr.

Dr. Herty became a member of the AIME in 1925, and for many years took an active interest in the work of the Iron & Steel Div. of our Institute. He was elected its Chairman in 1941. His services to the National Open Hearth Committee were of inestimable value because of his ability to make complex chemical and metallurgical reactions understandable to nontechnical steel mill operators.

He served with distinction on many committees of the Institute. In 1920 he received the Hunt Award. He was chosen in 1940 as the Howe Memorial Lecturer. During the years 1943 to 1947 he served on the Board of Directors of our Institute.

C. H. HERTY, JR.

Charles Herty served his country in World War I as a Sergeant in the Ordnance Dept. of the U. S. Army.

Over a period of many years he lent his energy, enthusiasm, and ability to many worthwhile activities. After graduating with honors from the University of North Carolina, and later from MIT, he became a teacher research associate, physical chemist and director of a metallurgical research board. In 1934 he cast his lot with Bethlehem Steel Co. He advanced to the responsible position of assistant to the vice-president of operations of that company which was his position when he passed away.

Charles Herty was the author of more than 80 technical and scientific papers. He was an honored member of a number of other technical societies. He pioneered in many improvements connected with the manufacture of steel, among which was the development of a viscosimeter for testing the quality of metallurgical slags. He perfected an improved method for removing manganese from open hearth slags.

Charles Herty will be greatly missed by his associates and host of friends. His genial smile and good humor; his willingness to help others; his sincere friendliness, and sterling character will long be remembered by those who had the good fortune to know him. He was a Christian gentleman in the true sense of the word.

NECROLOGY

Date Elected	Name	Date of Death
1940	Fred J. Bailey	Jan. 16, 1953
1948	Richard J. Barnes	Unknown
1899	John Cabot, Jr.	Dec. 8, 1952
1949	R. H. Clark	Nov. 24, 1951
1900	Howard N. Eavenson	Feb. 16, 1953
1951	John H. Gillies	Jan. 21, 1953
1896	Meade Goodloe	June 2, 1952
1940	John Harvey	January 1953
1947	Clyde T. Holmes, Jr.	Unknown
1936	Daniel B. Johnson	Aug. 16, 1952
1898	W. J. Loring	Oct. 8, 1952
1891	Arthur C. Payne	Nov. 13, 1952
1949	J. Irving Prest	May 29, 1952
1939	Charles F. Redmon, Jr.	August 1952
1935	Walter Riddell	Unknown
1921	Warren A. Sinsheimer	November 1952
1913	J. H. Steinmesch	Dec. 15, 1952
1938	F. E. Turton	Dec. 21, 1952
1952	Ward Tuttle	Nov. 30, 1952

Proposed for Membership
— Metals Branch AIME —

Total AIME membership on Feb. 28, 1953 was 18,262; in addition 2008 Student Associates were enrolled.

ADMISSIONS COMMITTEE

O. B. J. Fraser, Chairman; Philip D. Wilson, Vice-Chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, G. W. Lutjen, E. A. Prentis, Sidney Rolle, J. T. Sherman, F. T. Sisco, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

Alabama
Listerhill—Kennedy, Charles R. (J) (C/S—S-J)

California
Tarzana—Van Winkle, Delbert M. (M) (C/S—A-M)
Venice—Gassner, Robert H. (J)

Colorado
Denver—Schmuck, Howard K., Jr. (M) (R. C/S—S-M)

Connecticut
Litchfield—Christine, Richard J. (M) (C/S—J-M)
Waterbury—Kuzmenko, Peter (J)
Watertown—Chafey, James Edward (M) (C/S—A-M)

Illinois
Blue Island—Hays, Raymond H. (M) (C/S—A-M)
Chicago—Fleitman, Albert H. (J)
Chicago—Foss, F. William (J) (C/S—S-J)
Chicago—Tisinai, George F. (M) (R. C/S—S-M)

Indiana
Gary—Holt, John P. (M)
East Chicago—Strater, Theodore J. (J)

Massachusetts
Cambridge—Lement, Bernard S. (M) (C/S—A-M)

Michigan
Midland—Fredrickson, Jay W. (M) (C/S—J-M)
Midland—Saunders, William P. (M) (C/S—A-M)
Saginaw—Kubilins, Edward Theodore (M) (C/S—A-M)

Montana
Billings—Conrace, Joseph Cornacchione (M)

Nevada
Henderson—Herres, Schuyler A. (M) (R. C/S—S-M)

New Jersey
Montclair—Lambert, Vance E. (M)

New York
Long Island City—Chow, Joe G. Y. (M) (C/S—A-M)
Long Island—Sadofsky, Jerome (J)
New York—Campbell, John B. (J) (R. J)
Scotia—Ruggles, Rex. R. (A)

Ohio
Columbus—Robinson, Herbert A. (M) (C/S—A-M)
Lorain—Sattele, Louis F. (M)

Oregon
Portland—Vistica, Edward A. (M)

Pennsylvania
Munhall—Giove, John Laurence (M) (C/S—A-M)
New Kensington—Fitzgerald, Robert Dale (M) (C/S—A-M)
New Kensington—Nelson, Benny J. (M) (C/S—A-M)
New Kensington—Robinson, Donald L. (M)
Pittsburgh—Lankford, William T., Jr. (M) (C/S—J-M)
Pittsburgh—McCredie, John W. (M)
Pottstown—Hoff, Richard L. (M) (R. C/S—J-M)
Wayne—Ziesing, Robert A. (H) (R. C/S—S-A)

Tennessee
Oak Ridge—Adamson, George M., Jr. (M) (C/S—A-M)

Washington
Richland—Shupe, Owen K. (J) (C/S—S-J)

Australia
Port Kembla, N.S.W.—Knight, Ronald Leslie (M)

Brazil
Sao Paulo—Paliotta, Arnaldo (J) (C/S—S-J)

Canada
Ontario, Toronto—Latimer, George F. (J) C/S—S-J)

Japan
Tokyo—Katsuji, Nakanishi (M)

Peru
LaOroya—Lehto, Robert S. (J) (C/S—S-J)

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FASTER, MORE ACCURATE ANALYSIS
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Automatic Grating Spectrograph

Match this precise JAco Spectrograph against your *toughest* analytical problems. High reciprocal linear dispersion and maximum resolution mean easier and more accurate analyses of ferrous alloys, minerals, high temperature alloys and other materials with highly complex spectra. All-electric automatic operation assures foolproof control while saving time and steps. No finer spectrograph available for your research or industrial control applications.

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TECHNICAL FEATURES
- High reciprocal linear dispersion (5.0 A mm, Order I; 2.4 A mm, Order II; 1.6 A mm, Order III)
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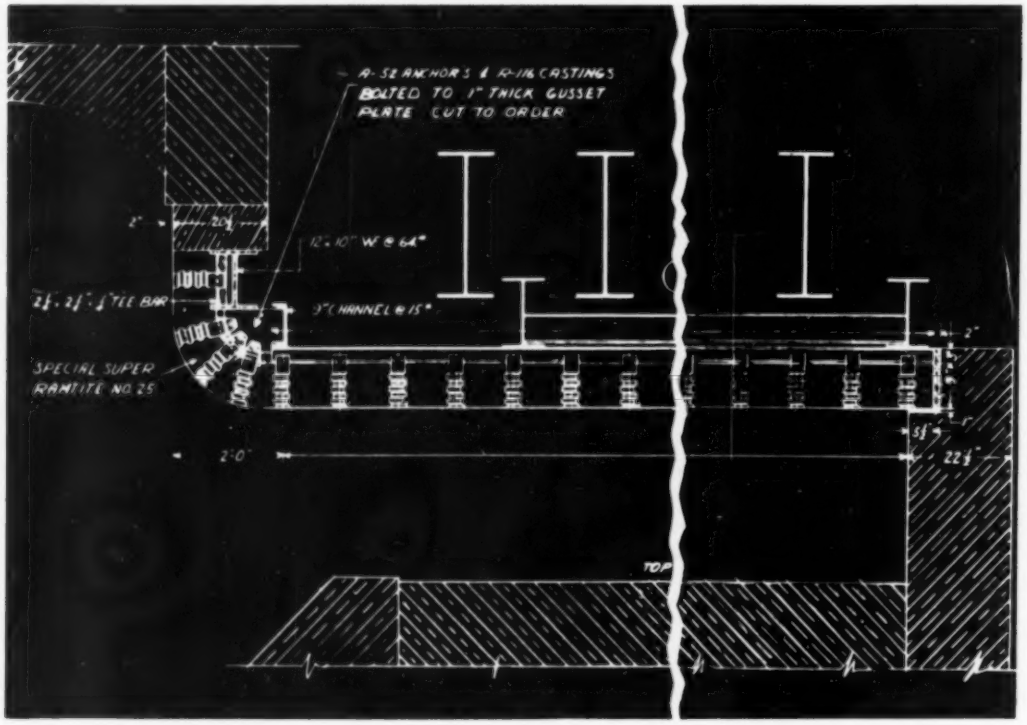
applied to open hearth furnace radial nose arch, fantail arch and checker chamber roof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12" 10" WT @ 64"
3" CHANNEL @ 15"
SPECIAL SUPER RAMTITE NO. 25
TOP

The tight monolithic structure, characteristic of Ramtite, practically eliminates air infiltration . . . a problem in present conventional refractory construction.

Ramtite is easily constructed in the fantail area to follow the outline of this passage without resorting to the intricate design of tile arches.

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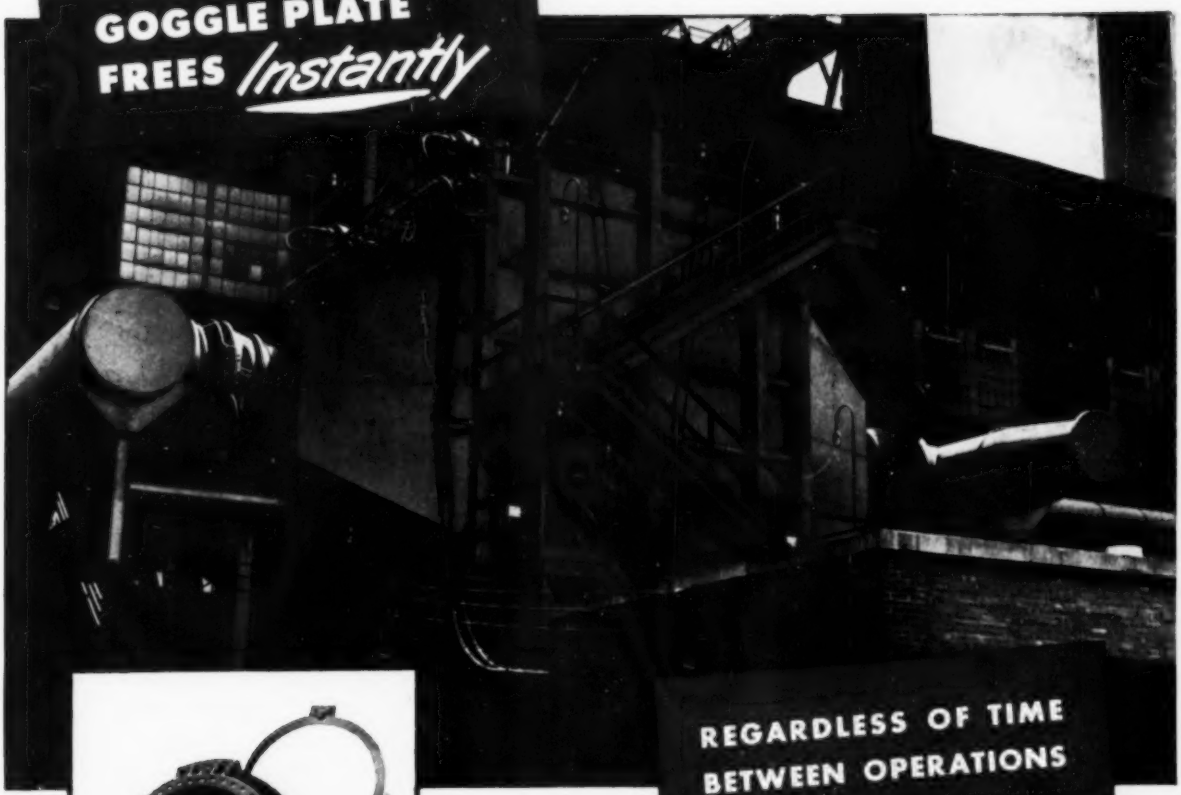
RAMTITE®

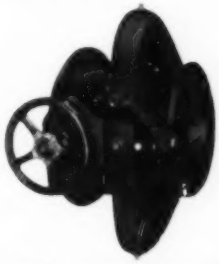
PLASTIC AND CASTABLE REFRACTORIES

GOGGLE PLATE
FREES *Instantly*



REGARDLESS OF TIME
BETWEEN OPERATIONS

60" x 48" Bailey Valve for horizontal gas main.



Totally enclosed type Bailey Valve for 6" diameter gas main.

Bailey Mechanical GOGGLE VALVES

No matter how long they remain unused, you can count on these valves to provide the tight, positive seal needed for shutting off gas mains in emergencies or for repairs. Requiring a minimum of maintenance, Bailey Mechanical Goggle Valves operate by a powerful clamping force which is applied equally to all points around the disc periphery. The goggle plate is freed by the same powerful mechanism. The safety and dependability of these valves have been thoroughly proved in service in gas washers, gas mains, coke plants and boiler plants. Available in sizes from 6" to 72", totally enclosed if desired.

WILLIAM M. Bailey COMPANY
ENGINEERS
LEADERSHIP THROUGH QUALITY

1221 BANKSVILLE ROAD PITTSBURGH 16, PA

*Lectromelt** BUS BARS go together faster in your plant because they're put together first IN OURS!

Dimensions and contours of this giant bus assembly were proved accurate here on templets matching those of the smelter to which it was shipped.

PRE-ASSEMBLY is standard practice at Pittsburgh Lectromelt Furnace Corporation. Furnaces too big for shipment in one piece are, nevertheless, completely unit assembled on our erection floor. So, too, are the huge copper bus conductors; drilled and bolted together to make certain every hole and every fitting matches—that the assembly follows every twist and turn expected of it.

You profit by this practice. Time spent in our plant is saved in yours, so your furnace gets into production sooner.

We help you in other ways.

Lectromelt engineers are familiar with the use of electric arc furnaces for smelting, refining and melting operations. They can help you select the Lectromelt equipment you need and will advise on the designing of your furnaces.

For Bulletin 104 telling you more about these furnaces and services, write Pittsburgh Lectromelt Furnace Corporation, 326 32nd Street, Pittsburgh 30, Pa.

Manufactured in . . . CANADA: Lectromelt Furnaces of Canada, Ltd., Toronto 2 . . . ENGLAND: Birlec, Ltd., Birmingham . . . FRANCE: Stein et Roubaix, Paris . . . BELGIUM: S. A. Belge Stein et Roubaix, Bresseux-Liege . . . SPAIN: General Electrica Espanola, Bilbao . . . ITALY: Forni Stein, Genoa. JAPAN: Daido Steel Co. Ltd., Nagoya

*REG. T. M. U. S. PAT. OFF.

MOORE RAPID

WHEN YOU MELT.. *Lectromelt*